1-1-1985

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INTRODUCTION

The Lake Char and Honey Hill faults in eastern and southeastern Connecticut (figure 1) are wide zones of mylonitization localized at the contact between Avalonian-aged metaplutonic and metasedimentary rocks and metavolcanic and metapelitic rocks of the Merrimack synclinorium. Locally, there is truncation of strata against the contact and units in the upper plate are drastically thinned against the fault (figure 2). In general, however, the faults are recognized as wide zones of mylonitization. The faults have been the subject of much speculation, as have their northward continuations (?) the Clinton-Newbury and Bloody Bluff faults. It is common for those who have not worked on these faults to consider them as sutures or major dislocations (e.g. Wilson, 1966) and for those who have worked on them to consider them as having displacements not exceeding several to possibly 10 kilometers (e.g. Castle et al., 1976). In addition to the tectonic significance of the faults, their sense of motion and timing has become a matter of considerable debate. Early workers (Lundgren et al., 1958; Dixon and Lundgren, 1968) considered the faults to be west-over-east (top up) thrust faults probably developed during the Acadian orogeny but with last motions no later than latest Paleozoic. This view (at least as regards to motion sense) is still widely held (e.g. Wintsch, 1979). Lundgren and Ebblin (1972) concluded that the Honey Hill fault represented a zone of very high strain with minimal displacement formed at the contact between basement and cover during basement diapirism. Mesoscopic and microscopic kinematic indicators (Goldstein, 1982a,b, 1984; Goldstein and Hutton, 1984) define top down (low-angle normal) motions. These data have led to the proposal of two new tectonic models for the formation of the faults: basement-cover decollement developed during basement diapirism (Goldstein, 1982a, b; similar to Lundgren and Ebblin, 1972) and low-angle normal faulting developed during extension (Goldstein, 1984). The timing of fault motion is (if that is possible) even more controversial than the motion direction, although there is a growing concensus that the latest episode of high-temperature mylonitization is of late Paleozoic age (O'Hara and Gromet, 1983; Hermes and Zartman, 1985; Wintsch, 1984; Goldstein, 1984). Goldstein, Rodman and Hutton (in review) suggest at least two episodes of high-temperature displacement based on studies along the Bloody Bluff fault. There, xenoliths of mylonite in a gabbro demand that mylonitization be no younger than Silurian and kinematic indicators describe motion as thrust with a left-lateral component. It is proposed (Goldstein, Rodman and Hutton, in review) that the Lake Char, Honey Hill and Bloody Bluff faults all experienced this pre-Silurian displacement and that the Honey Hill, Lake Char and possibly the Clinton-Newbury but not the Bloody Bluff faults were reactivated as low-angle normal faults in late Paleozoic time as a consequence of localized Alleghanian extension.

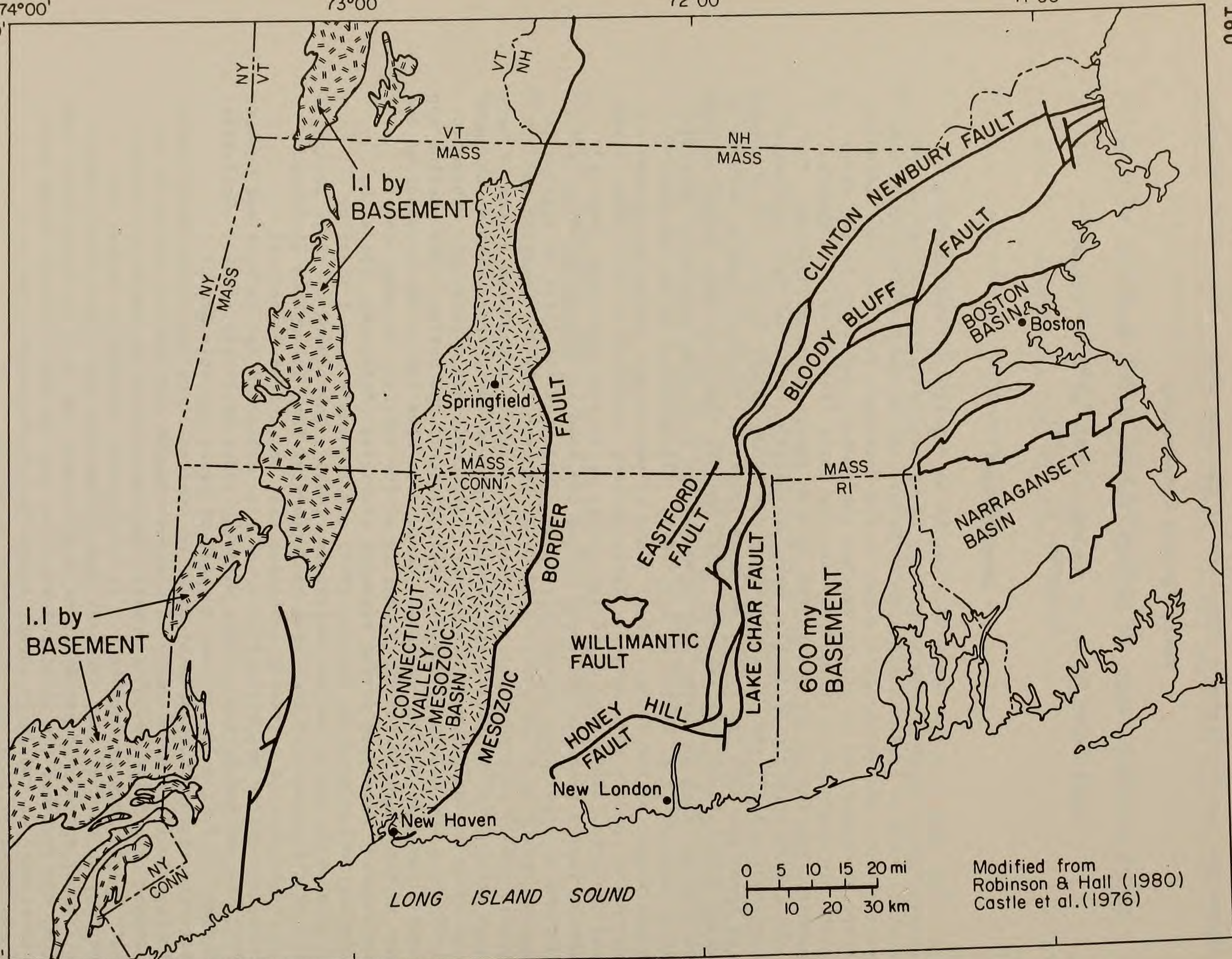


Figure 1. Schematic tectonic map of southern New England showing the location of faults of the southeastern New England fault system.

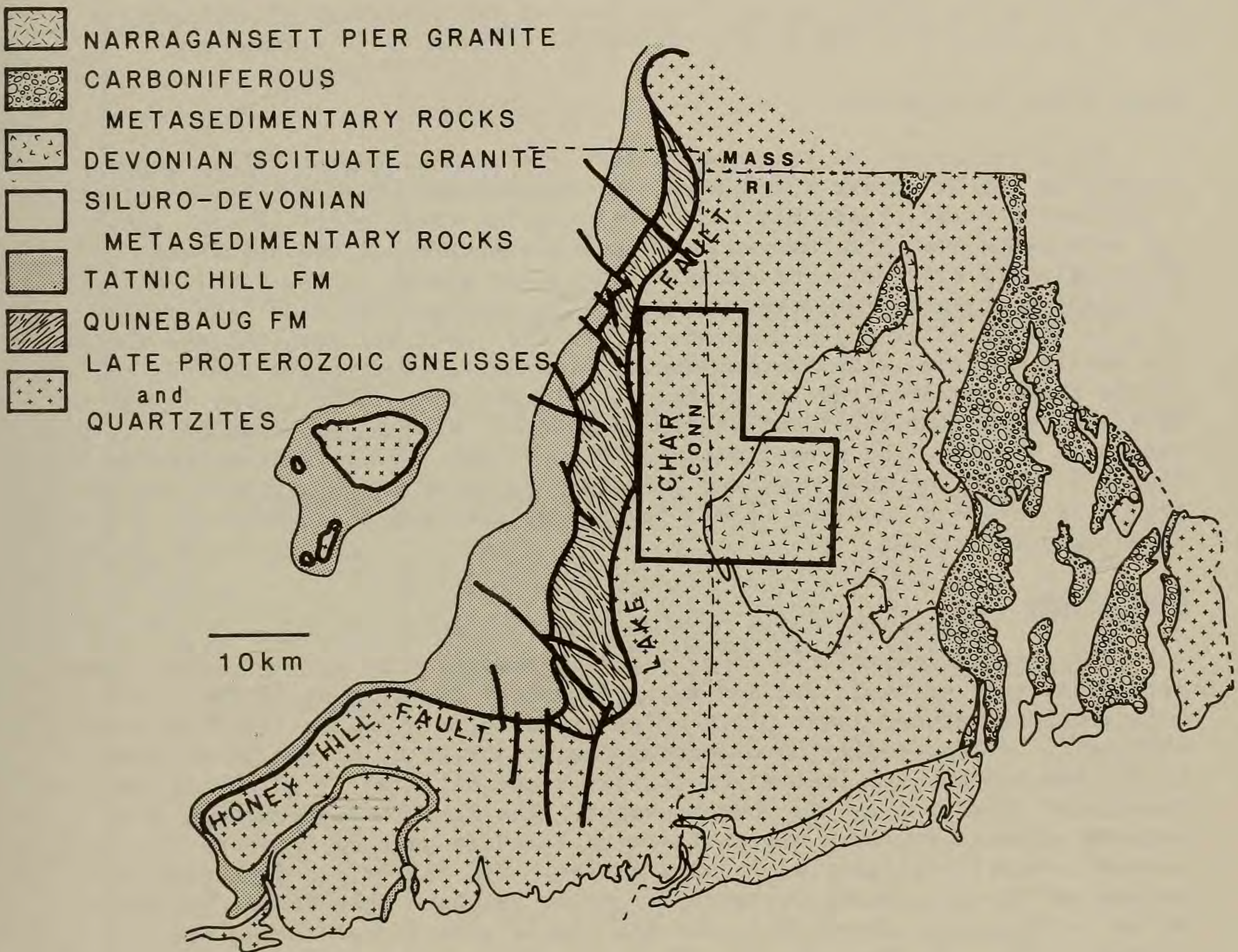


Figure 2. Oversimplified geologic map of Rhode Island and eastern Connecticut modified after Rodgers (1982) and Hermes and Zartman (1985). Unpatterned regions in southern Narragansett Bay are the Cambrian slates of Jamestown Island and Precambrian metamorphic and granitic rocks of Newport. Box is the area covered in Figure 4.

Stratigraphy

The rock units in and adjacent to the Lake Char-Honey Hill mylonite zone are conveniently divided into upper plate and lower plate although both Dixon (1968) and Snyder (1964) have mapped an upper plate unit in the lower plate. The distinction between upper plate and lower plate becomes confused at the western end of the Honey Hill fault where upper plate stratigraphy is infolded with that of the lower plate (Lundgren, 1962; Dixon and Lundgren, 1968; Goldsmith, 1976). An alternate view of the structure of the western end of the Honey Hill fault is presented by Wintsch (this volume).

Upper Plate Stratigraphy

The stratigraphy of the upper plate is dominated by the Putnam Group comprising the Quinebaug and Tatnic Hill formations. Despite the fact that a reasonable stratigraphy has been developed for these units (Dixon, 1964) and used successfully to map in the upper plate, most of the units are lithologically diverse. For example, the lower member of the Tatnic Hill formation contains a rusty-weathering gneiss, perhaps the most distinctive unit in the stratigraphy. However, within that unit are amphibolites which are easily confused with another Tatnic Hill unit, the biotite gneiss, and within those amphibolites are blocks of talc and actinolite (large enough to have been mined for talc) and layers of marble. With these kinds of variables in mind, the stratigraphy of Dixon (1964, 1976) is presented in figure 3. Only the most dominant lithology is noted in this figure and the reader is referred to Dixon (1964) for a more detailed discussion of lithologic variations.

Lower Plate

The stratigraphy of the lower plate is dominated by meta-granitic rocks with subsidiary metavolcanic and metasedimentary rocks. Many of the relationships between lower plate units are uncertain and correlations are difficult. Goldsmith (1976) describes the stratigraphy of the lower plate in the New London area (below the eastern Honey Hill fault) as having the Plainfield formation as its lowest member. The Plainfield formation is composed of massive, pure quartzites with a middle unit of (garnet) muscovite-biotite-plagioclase-quartz schist. The Plainfield formation is recognized in easternmost Connecticut (below the Lake Char fault) but much of the stratigraphy above it in the New London area is not recognized further north. The Mamacoke formation, the Monson gneiss and the New London gneiss comprises the upper sequence which consists generally of mafic to intermediate and felsic metavolcanic rocks (Goldsmith, 1976). In eastern Connecticut and Rhode Island the lower plate stratigraphy does not contain Goldsmith's (1976) upper sequence. The oldest rocks of that area are inferred to be the metasediments of the Plainfield Formation and those formerly assigned to the Plainfield Formation (Harwood and Goldsmith, 1971; Moore, 1983) or the "Metavolcanic Rocks" (Quinn, 1971), referred to here as the Unassigned Metasediments, which are differentiated from the Plainfield Formation only on the basis of their association with the Ponaganset Gneiss (figure 4). Both are loosely constrained to pre-date the latest Precambrian. An intrusive contact (??) between the Plainfield Formation and the Hope Valley Alaskite (601 ± 5 ma, zircon age, Hermes and Zartman, 1985) is observed at Stop 9. Similar tenuous intrusive relationships between the Unassigned Metasediments and the Ponaganset Gneiss (also late Precambrian,

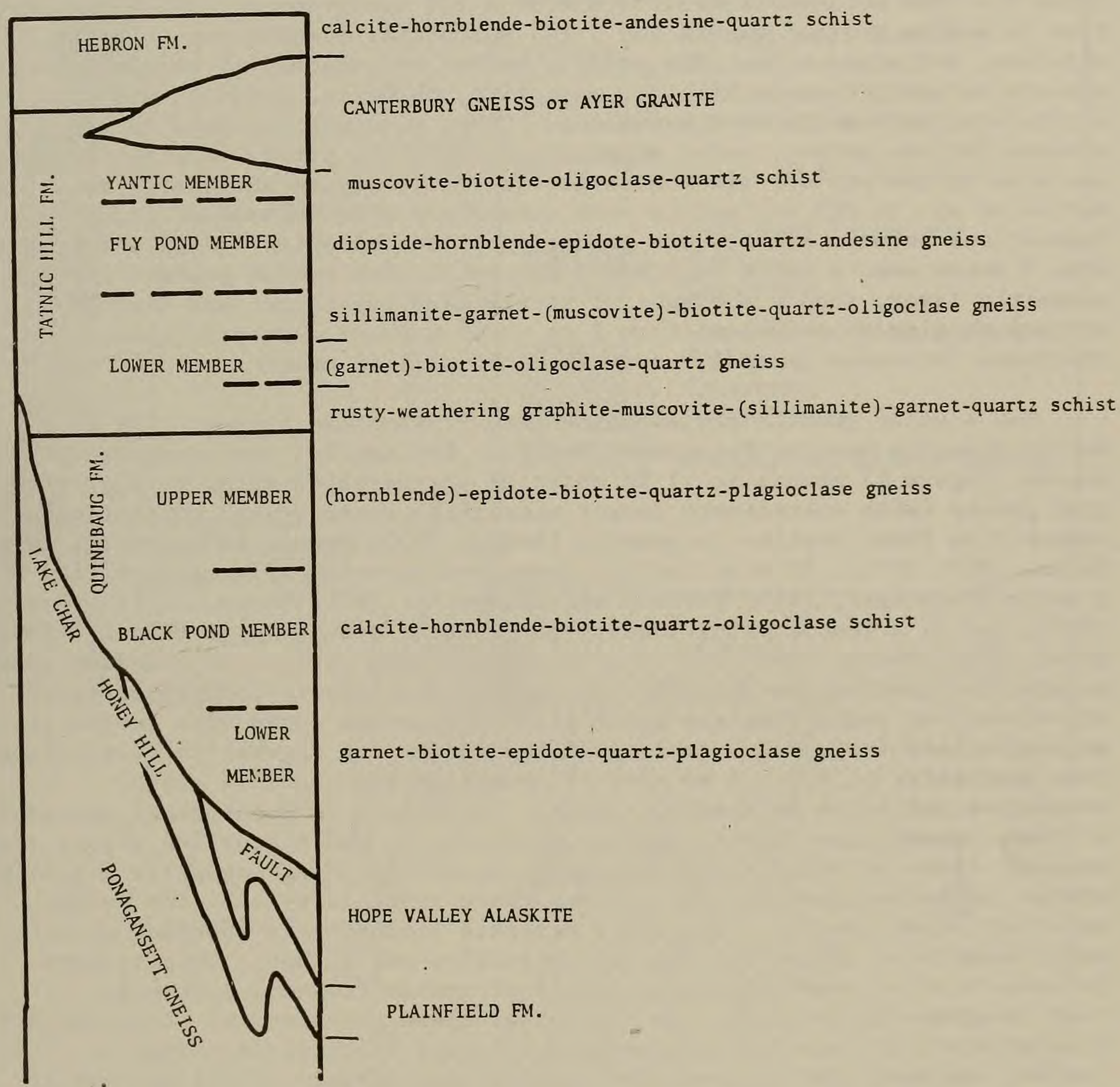


Figure 3. Stratigraphic column and rock descriptions for the eastern Connecticut region modified after Dixon (1964). Only the most dominant lithology is described, see text for further discussion especially of the lower plate.

L.P. Gromet, pers. com., 1985) at Ledge Road and Carbuncle Pond (figure 4) support a Precambrian age for the Unassigned Metasediments. Staurolite and kyanite have been found in the undivided metasediments at Carbuncle Pond (G. Moore, pers. com., 1984; Pope, 1976).

The Plainfield Formation is divided into eastern and western massive, metaquartzarenite members (Stop 7) and an intervening central pelitic membr (Stop 8). The metaquartzarenites are 90 - 97% equigranular, recrystallized, fine to medium grained quartz and 3-10% muscovite, plagioclase, biotite, chlorite, and actinolite. The pelitic member is composed of thinly layered schists variably rich in biotite, muscovite, chlorite, epidote, and actinolite, and quartz rich psammites. Other minerals observed in the schists include garnet, sodic plagioclase, calcite, pyrite, and hornblende. Isolated in the schists are boudinaged quartzite layers and quartz veins and bodies of up to 90% actinolite with subsidiary plagioclase and quartz. Transitions between members are gradational, one of which is well exposed at Stop 8 where over a 100 m interval a muscovite rich schist grades, through a psammitic layer, into a sequence of interbedded quartzites and biotite schists ranging in thickness from 2 cm to 15 m where quartzite layer thickness increases generally away from the pelitic member.

Two similar granite gneisses are Late Precambrian in age: The Hope Valley Alaskite and the Ponaganset Gneiss. Regionally, the Ponaganset Gneiss (figure 4) occurs as 1) an andesine phenocryst-bearing porphyritic gray gneiss (with subordinate larger microcline phenocrysts) which ranges in composition from tonalite to granite (Acker, 1950; Frost, 1950; Moore, 1963; Quinn, 1967; 1971), 2) a microcline phenocryst-bearing gray porphyritic granite (Feininger, 1965; Harwood and Goldsmith, 1971; Dixon, 1974; Moore, 1983), and 3) a leucocratic, locally porphyritic pink granite (Frost, 1950; Quinn, 1967; Moore, 1983). At Stop 5 the dominant variety is a medium gray, porphyritic granite gneiss. The 2-4 cm pink phenocrysts (porphyroclasts) are microcline and orthoclase patch perthites (often cored with subhedral, 2 mm plagioclase inclusions) recrystallized in varying degrees to plagioclase free aggregates of 0.5 - 5 mm microcline grains with sutured grain boundaries and broad deformation bands. The matrix is a polygonal aggregate of fine, equant, low strain, quartz, plagioclase, and microcline grains with abundant clots of biotite and accessory phases including magnetite/ilmenite, sphene, allanite, apatite, and zircon. Dark green hornblende can be an important phase locally. Secondary minerals include very abundant epidote and clinozoisite, chlorite, and rare muscovite and garnet. This variety includes 0.1-1 m xenoliths (autoliths?) of medium grained, dark gray tonalite-granodiorite with rare 2 cm plagioclase phenocrysts. Both are cut by a porphyritic leucocratic granite which has, (although depleted in biotite, epidote, and clinozoisite) similar petrography to the porphyritic gray granite. This is interpreted as a leucocratic facies of the Ponaganset Gneiss. Arguments that support a common path of evolution for the tonalite, the porphyritic gray granite, and the porphyritic leucocratic granite include 1) a mutual linear covariance of modal and geochemical data, 2) similar accessory mineral assemblages, 3) similar phenocrysts in the porphyritic gray and the leucocratic granites, and 4) the cross cutting relationships seen in outcrop. These are tentatively termed the andesine, microcline, and leucocratic varieties of the Ponaganset Gneiss.

The Hope Valley Alaskite is also late Precambrian and is a very leucocratic, medium grained, rarely porphyritic, pink granite (Moore, 1963;

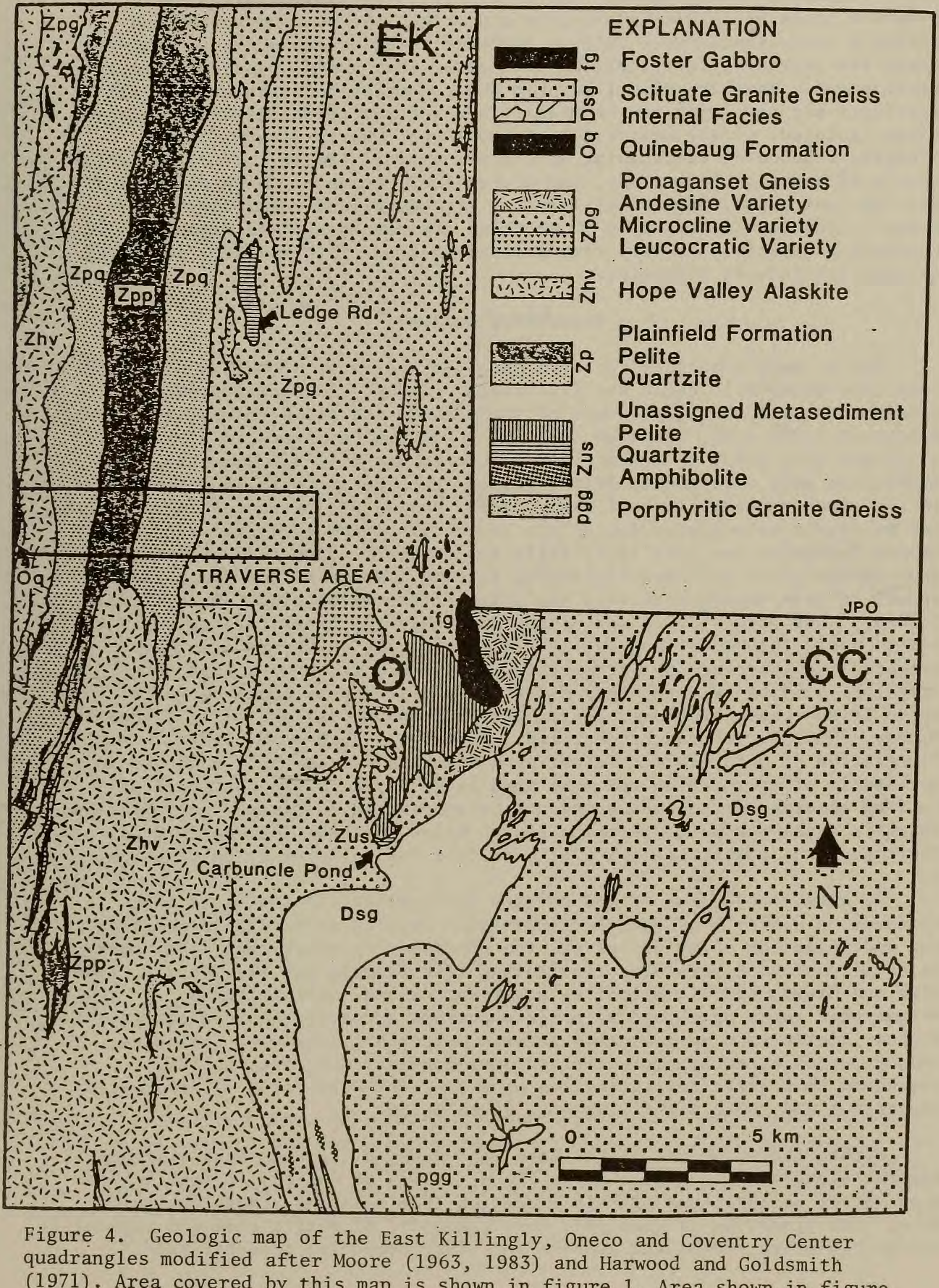


Figure 4. Geologic map of the East Killingly, Oneco and Coventry Center quadrangles modified after Moore (1963, 1983) and Harwood and Goldsmith (1971). Area covered by this map is shown in figure 1. Area shown in figure 11 is noted by the rectangle labeled traverse area.

1983; Feininger, 1965; Harwood and Goldsmith, 1971; Day et al., 1980). It commonly contains 5-10 mm microcline and orthoclase vein perthites and slightly subordinate, well twinned subhedral plagioclase grains. Commonly these are partially recrystallized and often show grain boundary sub-grain development. Many are also fractured where complex networks of very thin fractures are developed in the plagioclase and the perthites are displaced along isolated, wider, matrix filled fractures. Quartz occurs as very elongate ribbons of rectangular undulatory grains, and in a fine, polygonal matrix of quartz, plagioclase, and microcline. Accessory minerals include biotite, muscovite, magnetite/ilmenite, zircon, allanite and very rare garnet. Locally layers up to 10 cm thick are devoid of k-feldspar and are composed principally of very fine-grained quartz. This may be a result of deformation-induced diffusion.

Structural Geology

The primary structural problem concerns the sense of motion(s) on the Lake Char-Honey Hill fault and its (their) timing. A related problem concerns the structural sequence of rocks above and below the mylonite zone. Goldstein (1982 a,b), based on detailed structural analyses in a small area, concluded that prior to mylonitization the Tatnic Hill and Quinebaug formations were isoclinally folded twice. Peak metamorphic conditions were in the upper amphibolite (sill-ksp) facies during the first folding and were not seriously retrograded during the second isoclinal folding. The younger Hebron formation was only isoclinally folded once. Both rock sequences experienced local post mylonitization folding. Rocks of the lower plate appear to have experienced only one phase of pre-mylonitization isoclinal folding. One of us (J.O.) speculates that this isoclinal folding could be due to early thrust motions on the Lake Char fault which may also have resulted in high-over-low metamorphic zonations. It appears that this isoclinal folding is a regional event as it is commonly observed in the Rhode Island basement (lower plate) (Harwood and Goldsmith, 1971; Skehan and Murray, 1980; Barosh and Hermes, 1981; Skehan, 1983; Barosh, 1984). Correlation of deformations across even moderate distances is a matter dominantly of speculation and more work is required before the isoclinal folding observed in various areas can be correlated in time. The foliation which is axial-planar to isoclinal folds below the Lake Char-Honey Hill fault zone was reactivated as a slip surface during later mylonitization.

As noted above, one of the primary features of the faults is the presence of a wide zone of mylonitization. Despite considerable progress in our understanding of mylonites and the processes by which they form, there is still confusion regarding terminology (for example see Wise et al., 1984, 1985 and Mawer, 1985). Mylonites are fine-grained, well-foliated metamorphic rocks which had as their precursor a coarser-grained equivalent. A clear distinction must be made between mylonites, involving grainsize reduction dominated by crystal-plastic mechanisms, and cataclasites, dominated by brittle fracturing. A more thorough discussion of deformation mechanisms and their significance is given below.

Within the mylonites of the Lake Char-Honey Hill fault zone a strong mineral elongation lineation marks the direction of motion. Figure 5 shows mean vector orientations of this lineation from subareas along the fault zone. The lineation is composed, most commonly, of quartz rods and ribbons, elongate biotite flakes and streaks and (less commonly) feldspar rods.

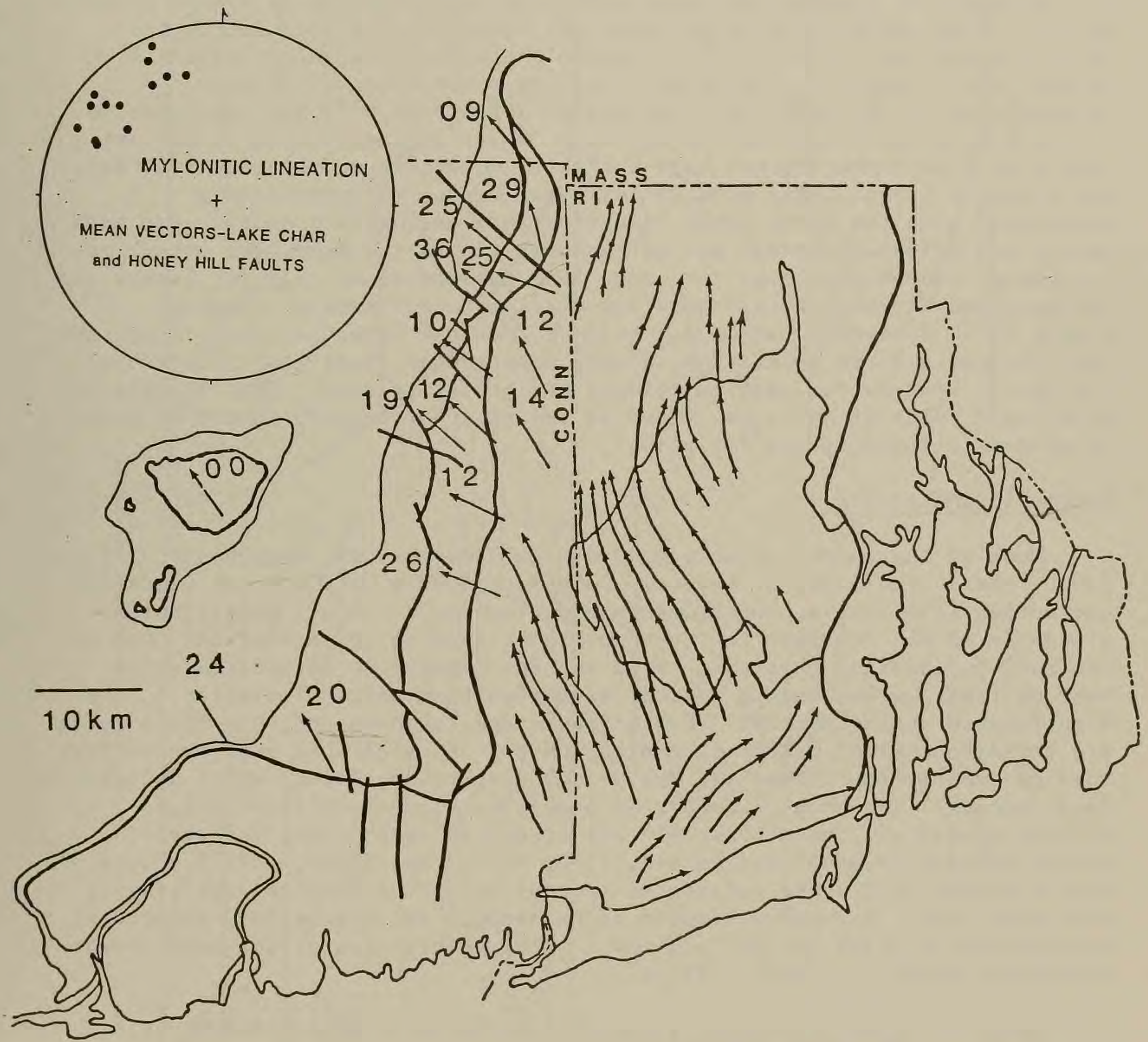


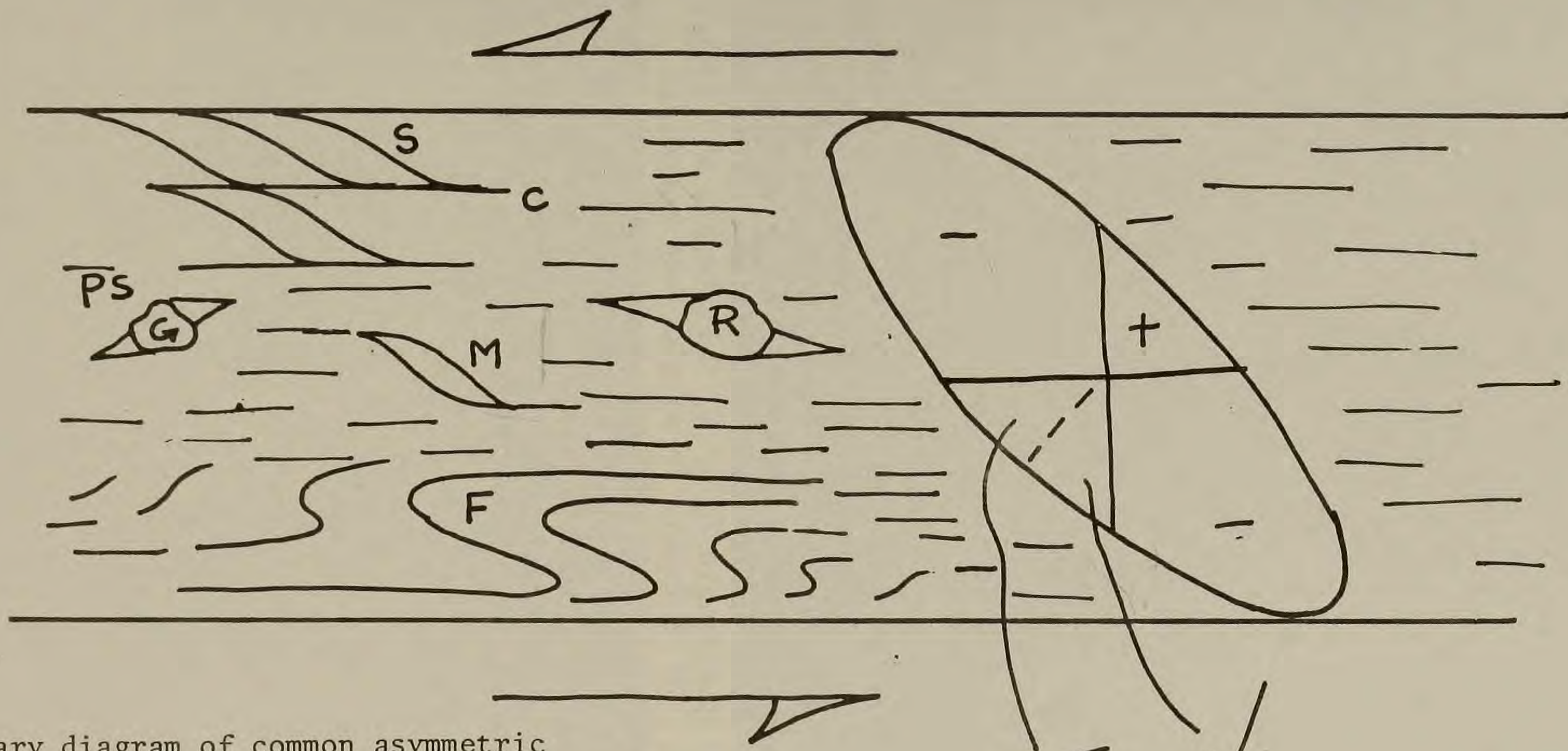
Figure 5. Lineation summary of the Lake Char-Honey Hill fault zones. Arrows with labeled numbers represent vector means of field data from one quarter areas of $7\frac{1}{2}$' quadrangles. The lower hemisphere equal-area diagram shows those vector mean orientations. Data for the Willimantic Dome (labeled 00) are taken from Wintsch (1982). Shown in the long, unlabeled arrows are the lineation trends of Day et al. (1980). See text for further discussion.

Despite small angular differences in the orientation of lineations, the pattern is one of a consistently northwestward trending motion direction. Also shown on Figure 5 is a summary of lineation trends from Day et al. (1980) for the area east of the Lake Char fault. O'Hara and Gromet (1984) speculated that the northwest trending lineations of the Lake Char fault merge smoothly with north-south lineations. They interpret this as relating to a major, north-south striking shear zone. Within this shear zone (Stop 5) the lineation plunges shallowly northward and foliation is almost totally absent. Right-lateral shearing along the lineation has been documented (O'Hara and Gromet, 1984, 1985). Toward the Lake Char fault, foliation becomes more dominant. The transition from north-south lineation orientations to northwest orientations is abrupt (Stop 8) and the relative timing of the two lineations is unclear. There is some reason to believe that Lake Char movements may have outlasted movements to the east in O'Hara and Gromet's (1984, 1985) Hope Valley shear zone. Microstructures associated with the north-south lineations are exclusively ductile for both quartz and feldspar whereas microstructures within the Lake Char mylonites (northwest lineations) span the range from ductile to brittle for quartz and feldspar and ultramylonite layers and dikelets occur locally (Stop 10, figure 7F). Currently, we do not believe that the Lake Char fault forms the less sheared western boundary of a more fundamental shear zone located to the east. Post-mylonitization folding is locally present. This is seen as mesoscopic folds of mylonites (Stop 3) and as a north-south spread in poles to mylonitic layering and foliation.

Kinematic Indicators

Much of the current controversy surrounding the Lake Char-Honey Hill fault regards the sense of motion. Goldstein (1982a,b; 1984) and Goldstein and Hutton (1984) have proposed top-down (low-angle normal) motion which stands in marked contrast to the traditional view of thrust motion. One of the main purposes of this trip is to examine mesoscopic structures which bear on fault motion and to present microstructural data of similar significance at the outcrop. Participants and followers of this field guide are urged to collect oriented samples and cut oriented thin sections so that they can verify for themselves the microstructural asymmetry which defines fault motion. Recently, a number of papers have been published which discuss mesoscopic and microscopic structures in shear zones and their interpretation (Simpson and Schmid, 1984; Lister and Snoke, 1985). These papers should help those interested in confirming (or denying) the results presented here. A summary diagram of mesoscopic and microscopic structural asymmetries is shown in figure 6 and a brief description of the more common asymmetric microstructures follows.

Composite Planar Fabrics (C and S) - First described by Berthe et al. (1979), these non-parallel planar fabrics are considered to be one of the most reliable shear sense indicators. In the "traditional" sense, C (cisaillement) planes are parallel to shear zone boundaries and represent zones of high shear strain; S (schistosite) is a grain shape foliation related (perhaps) to the accumulation of finite strain. Thus, in the initial stages of shear, the angle between C and S should be approximately 45^{o} and should decrease as shear strain accumulates. There is some debate over the timing of formation of C planes relative to S. This, however, is not significant to shear sense determination. It need only be established that S curves into C, the sense of obliquity will define the shear sense.



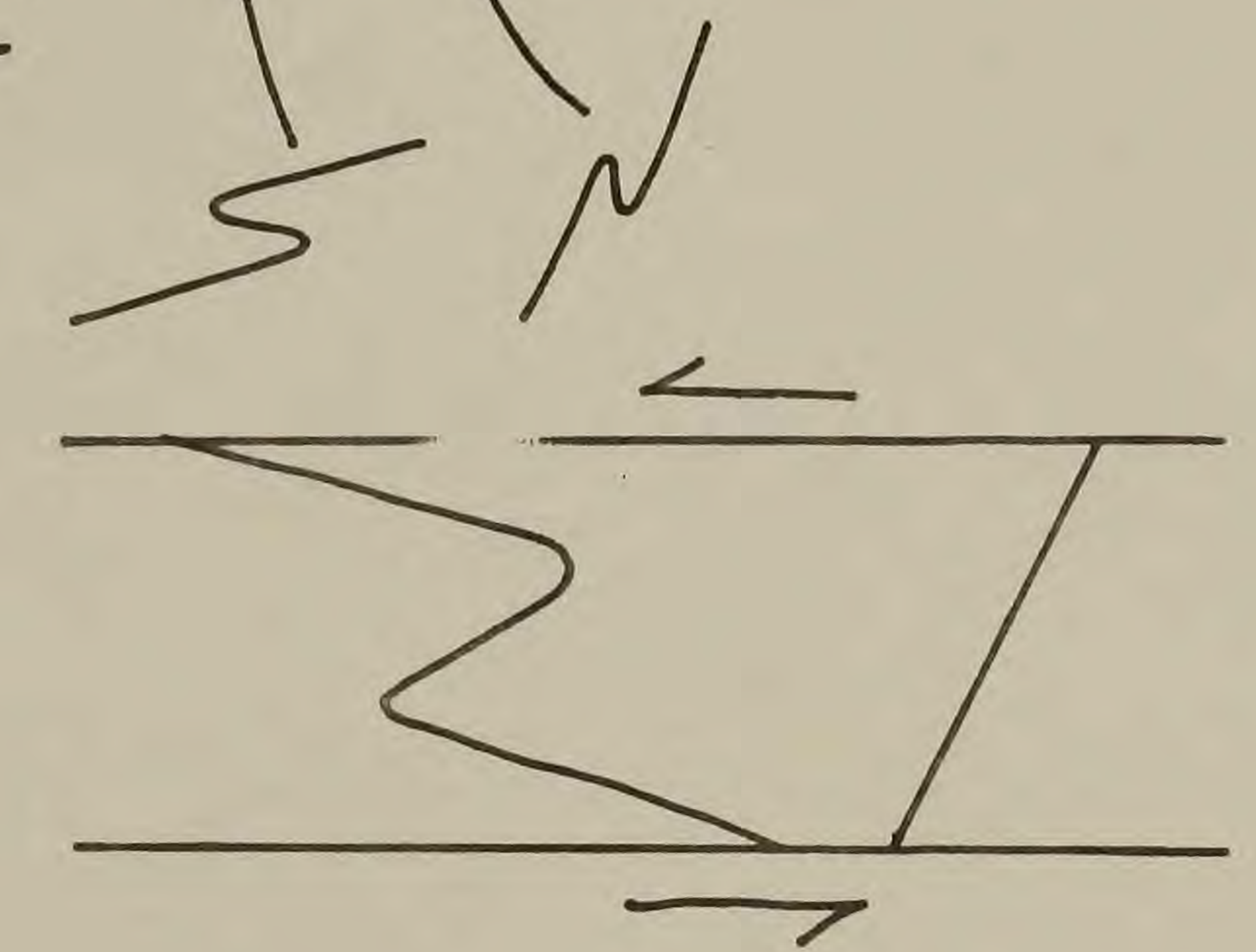
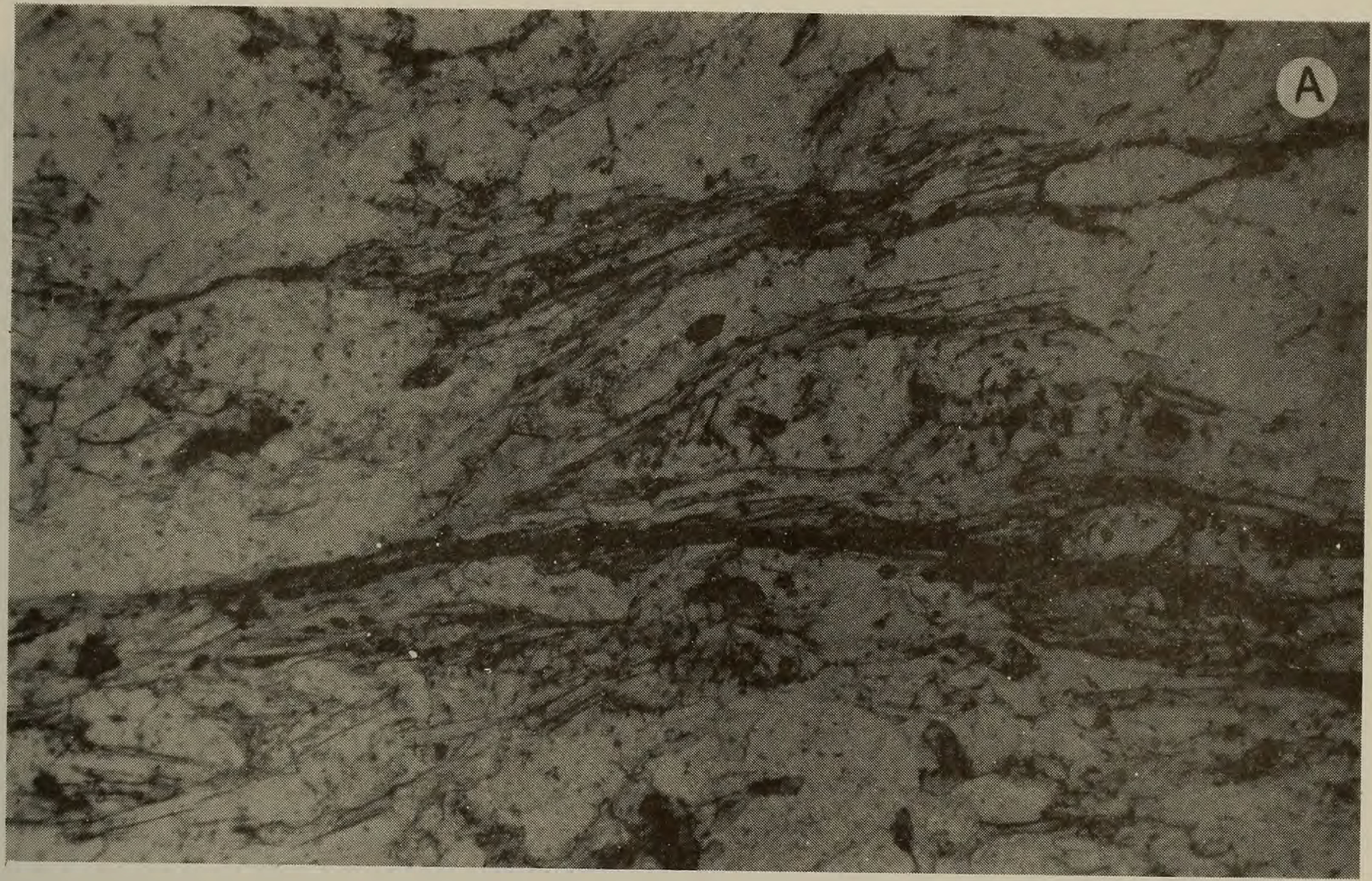


Figure 6. Summary diagram of common asymmetric structures in shear zones: S and C - schistosite and cisaillement fabric (Berthe et al., 1979); PS - pressure shadows around megacryst; M - mica "fish"; R - recrystallization tails on asymmetric augen; F - asymmetric intrafolial folds. Also shown (schematically) is a strain ellipsoid representative of the instantaneous state of strain; negative and positive refer to orientations of features which would experience extension or compression respectively. The two regions of the positive segment would have different fold asymmetries. Shown to the right is the model of Bell and Hammond (1984) for forming asymmetric folds by shearing at the margins of a shear zone. See text for further details.

Figure 7. Typical microstructures in mylonites from the Lake Char-Honey Hill fault. All photomicrographs are from thin-sections cut parallel to lineation and perpendicular to foliation with the down-plunge direction of lineation on the right. A - S and C defined by biotite flakes in the Plainfield Formation; Thompson quadrangle, intersection of Tucker Hill Road and Route 44 (Stop 11, this trip), photograph is approximately 1 mm across; B - Large muscovite "fish" in mylonitized Biotite Gneiss of the Lower Member of the Tatnic Hill Formation, Fitchville quadrangle, 150 m south of Stop 2 (this trip), photograph is approximately 2 mm across; C - Oblique quartz grain shape from same locality as A, photograph is approximately 2 mm across; D - Oblique quartz grain shape, subgrain development and asymmetric recrystallization tails in plagioclase augen in mylonitized Biotite Gneiss of the Lower Member of the Tatnic Hill Formation, intersection of Bishop Road and South Road, Fitchville quadrangle (Stop 2, this trip), photograph is approximately 2 mm across; E - Microfaults in plagioclase megacryst from mylonitized Quinebaug Formation, north of Squaw Rock Road, southeastern Danielson quadrangle, photograph is approximately 2 mm across; F - Ultramylonite layer and dikelets in mylonitized Fly Pond Member of the Tatnic Hill Formation, Fitchville quadrangle, 500 meters west of Stop 2 (this trip), photograph is approximately 2 mm across.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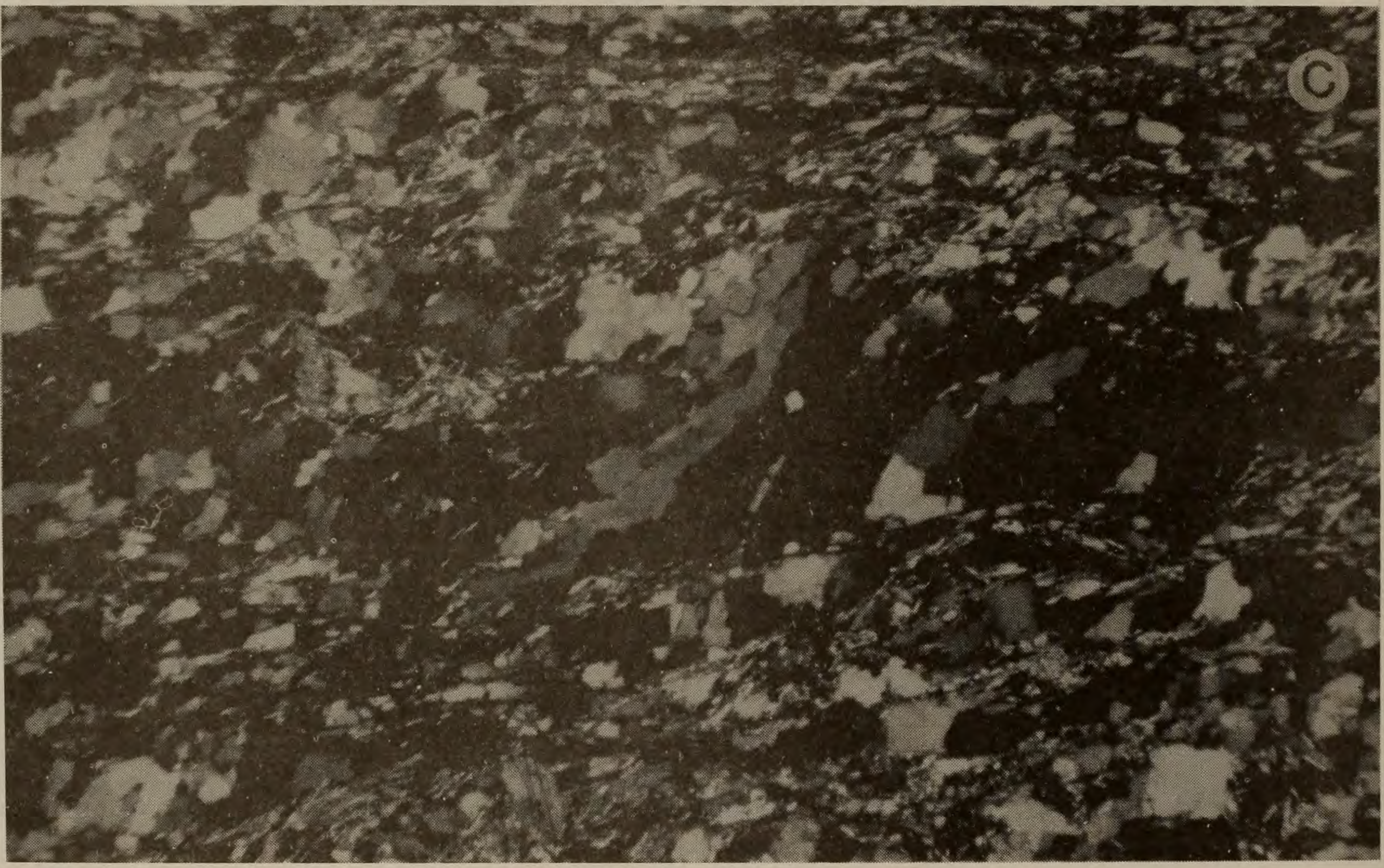
B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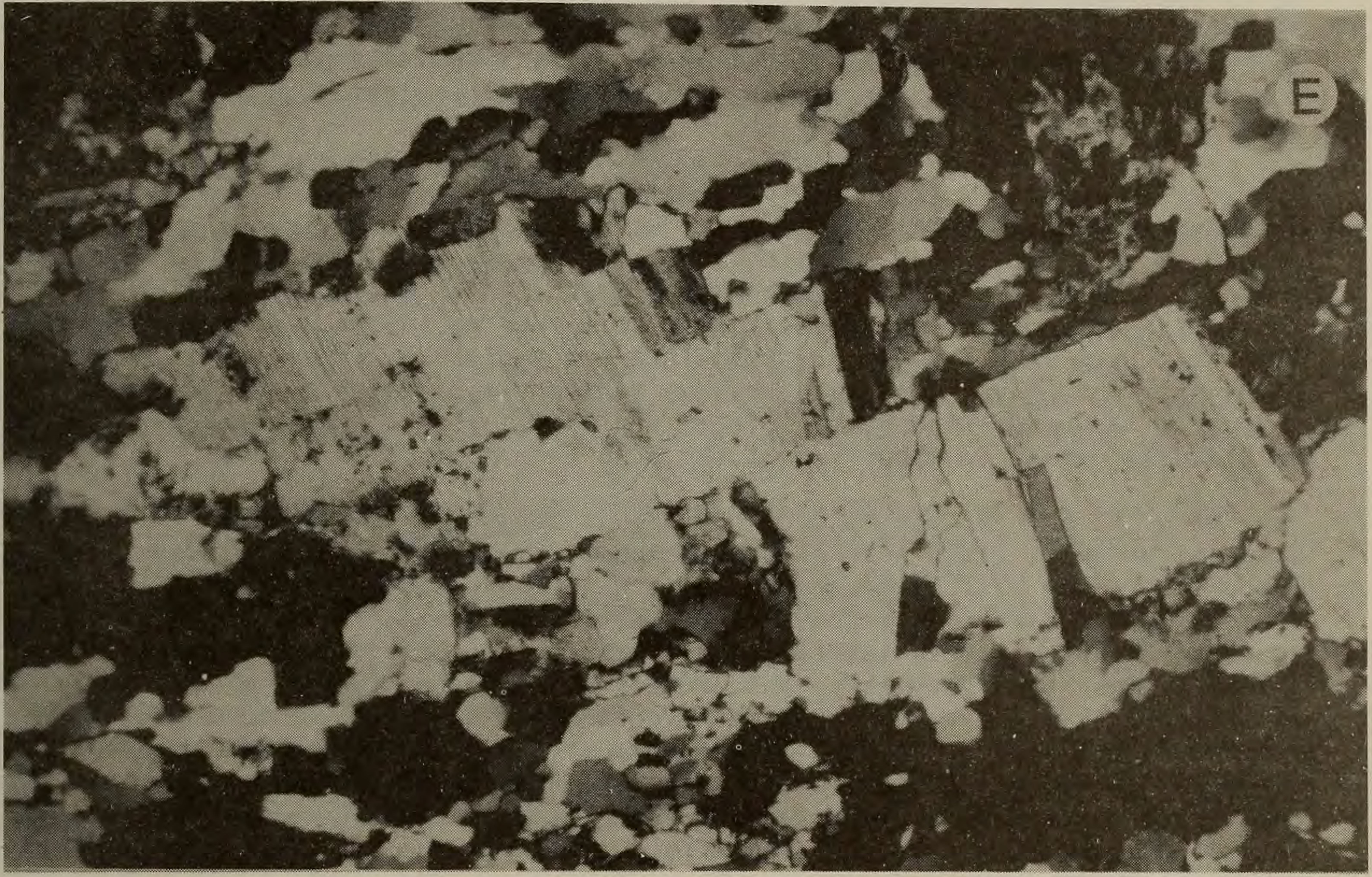
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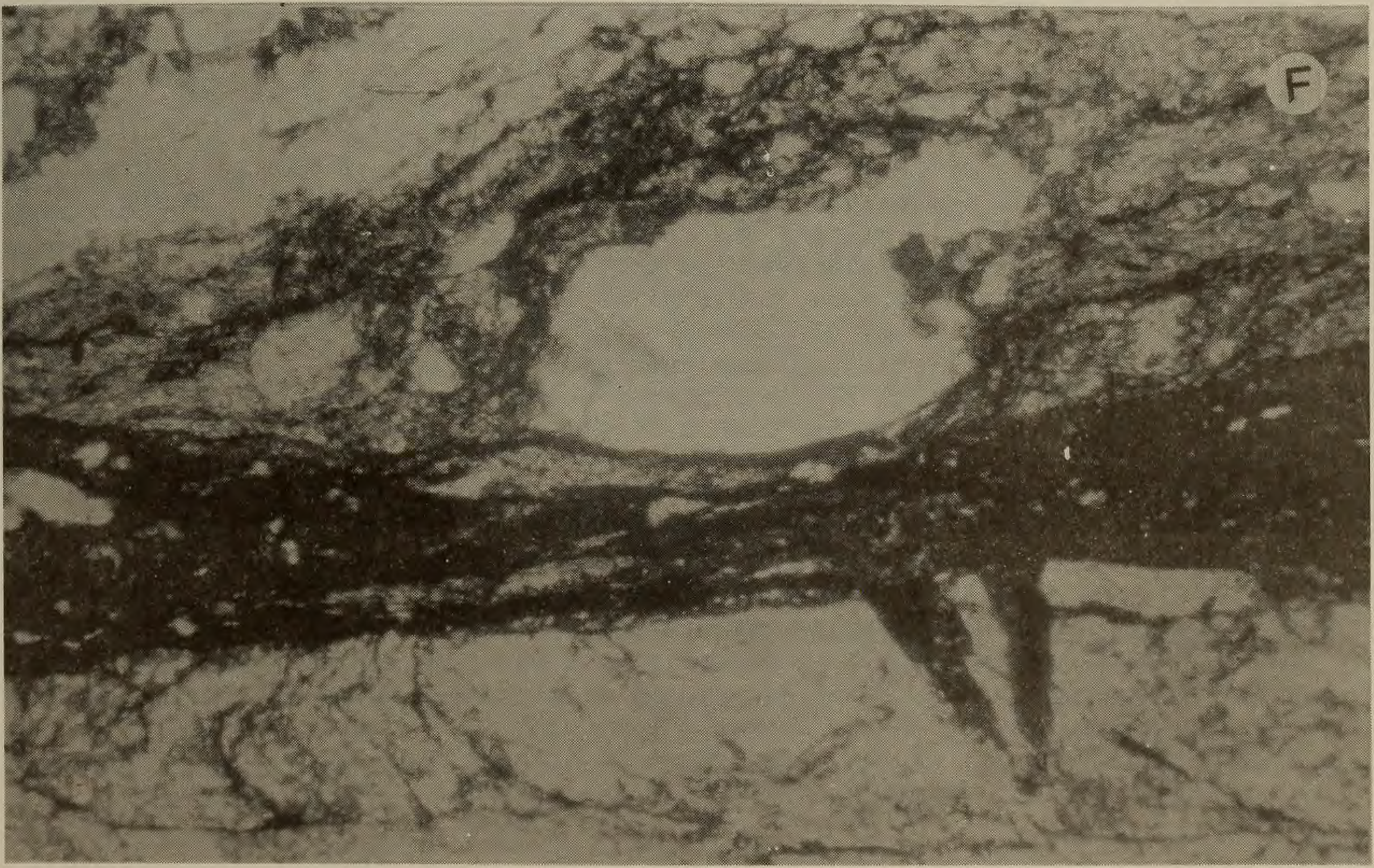
F

This fabric is locally well-developed in the Lake Char-Honey Hill mylonites. It is best seen in pegmatites within the Fly Pond Member of the Tatnic Hill Formation in the Fitchville quadrangle (Stop 1), in the Hope Valley Alaskite in the East Killingly quadrangle (Stop 9) (only obvious on cut and stained slabs) and in thin sections of the Plainfield Fm. from the Thompson quadrangle (Stop 11, figure 7A).

Lister and Snoke (1985) have suggested that mylonites with oblique, composite fabrics should be considered as a separate broad class of mylonites, S-C mylonites, of which there are two types. Type I is characterized by C and S in the sense of Berthe et al. (1979) (described above) and are common in deformed plutonic rocks, as in the Hope Valley Alaskite (Stop 9). Type II S-C mylonites are defined by other composite planar fabrics, mica "fish" and oblique quartz grain shapes, and are common in quartz- and mica-rich rocks (Lister and Snoke, 1985). These fabrics are exceedingly common in mylonites of the Lake Char-Honey Hill faults.

Mica "Fish" - Muscovite in mylonites is frequently quite large despite the small grain size of most phases, including biotite. These large muscovite grains will commonly take on a sigmoidal shape or form "stairs" connecting C-planes. They have been referred to as mica "fish" and are another reliable, easily interpreted kinematic indicator. Lister and Snoke (1985) suggest that very large muscovite grains are boudinaged or cut by listric normal microfaults when they are inclined to the shear zone boundary such that they will experience instantaneous extension (figure 6). The boudin or fault "blocks" are eventually separated along C-surfaces, their tails experience intense dynamic recrystallization and merge sigmoidally into the C-planes. The sense of obliquity and sigmoidal rotation are excellent shear sense indicators. These "fish" are exceedingly common in the metasedimentary rocks of the upper plate (figure 7B, Stops 1 and 2) and, locally, in the Hope Valley Alaskite (Stop 4).

Oblique Quartz Grain Shapes - Because quartz so easily experiences dynamic recovery and recrystallization, it is able to develop a grain shape which is directly related to the sense of shear. Syntectonic recrystallization results in equant quartz grains; these grains will then act as small strain indicators, elongating initially at about 45° to the shear zone boundaries (C-planes) and then at progressively lower and lower angles until further recrystallization produces a new equant fabric. Further shear strain then acts in a similar fashion on this equant fabric. Because micro-scale domains may undergo dynamic recrystallization at different stages of deformation, one thin section might have quartz grain shapes at angles of 40° to 10° to C-planes (Lister and Snoke, 1985). Oblique quartz grain shapes are common in all quartz-rich rocks of the Lake Char-Honey Hill mylonite zone. They are especially common in the Plainfield quartzite (Stop 11, figure 7d), in the mylonitized Hope Valley Alaskite (Stop 4 and 9, figure 7C) and in the Tatnic Hill formation (figure 7D, Stop 1 and 2).

Quartz C-Axis Orientation - Crystallographic preferred orientation of quartz c-axes developed by progressive simple shear is one of the most widely discussed topics in the structural literature. It is not easily interpreted, although it is a commonly used technique. Among the difficulties relating to the development of crystallographic preferred orientation are the relative dominance of slip on basal versus prismatic slip planes (Simpson and Schmid, 1984), late stage reorientation of the bulk slip plane due to folding (Carreras et al., 1977), and the component of pure shear involved in the deformation (Wenk et al., 1984). Despite these uncertainties, the C-axis fabric is commonly interpreted with respect to shear sense when either a "skeletal" fabric defining cross-girdles (Lister and Hobbs, 1980) or a point maximum misoriented with respect to the foliation and lineation is observed. The reader is referred to Simpson and Schmid (1984) for a more thorough discussion.

Mesoscopic Asymmetric Intrafolial Folds - Folds in mylonites which have axial planes at low-angles to the mylonitic foliation, deform the mylonitic layering and foliation, have an axial plane foliation which is essentially mylonitic and decrease in amplitude along their axial planes (figure 6) are common in many mylonite zones, including the Lake Char-Honey Hill fault zone. Axes of such folds commonly conform to a separation-angle geometry and have been used to determine the shear sense of the Lake Char-Honey Hill fault (Goldstein, 1982 a,b). The origin of such folds and thus, their interpretation with respect to shear sense is uncertain and is a topic of debate in the literature (e.g. Huddleston, 1983; Platt, 1983 ; Bell and Hammond, 1984). Folds developed in dikes and veins are used with great caution because the rotation sense of the fold as well as the orientation of its axis depends on the initial orientation with respect to the shear zone (Figure 6). Folds developed in mylonitic layering and foliation should be more easily interpreted but their origin is unclear. Layering and foliation in shear zones should roughly parallel the X-Y plane of the bulk strain ellipsoid and because mylonites are the expression of high shear strains, the layering and foliation are sub-parallel to the shear zone boundaries. Planar features, such as mylonitic layering and foliation will deform in accord with their orientation with respect to the instantaneous state of strain in the shear zone and will rotate with respect to the shear zone. Thus, they should always lie within the field of instantaneous finite elongation, cannot rotate through the plane of the shear zone and thus, should not fold. This, of course, assumes homogeneous simple shear which probably never represents reality. There are currently two viable mechanisms to explain the origin of folds in shear zones. Huddleston (1983) argues that folds will only develop when layering is inclined to the shear plane. He explains the origin of folds in glacial ice as the result of such a discordance when a glacier flows over a discontinuity (a hill) as its base. On the down-flow side of the hill, the layering is inclined steeper than the flow planes and folds result which have asymmetries in harmony with the direction of glacial flow (sense-of-shear). Talbot (1979) uses a similar mechanism to explain folds in flowing salt glaciers. Bell and Hammond (1984) also rely on a similar mechanism to explain folds in mylonites. In their model, folds develop on the down-flow side of ellipsoidal pods of less deformed rock. Although they urge great caution in the use of folds as shear-sense indicators, they note that they are potentially useful.

A very different mechanism has been proposed by Platt (1983). Based on a mathematical model involving variations in the rate of shear along layering, Platt (1983) shows that folds with vorticities of both equal and opposite signs to that of the shear (equal and opposite rotation sense) will initiate depending on whether the rate of change of shear on layering is faster or slower than that surrounding it. Platt (1983) further shows that folds which initiate with rotation senses the same as the shear zone will continue to develop whereas those with opposite senses of rotation will devolve with progressive deformation. We prefer the model of Platt (1983) to explain most of the folds observed in the Lake Char-Honey Hill mylonite zone because the presence of less deformed pods with anastomosing mylonites is only rarely observed and is not present where folds are best developed. Thus, although fold asymmetry is controversial and must be used with caution, we believe that it can be a reliable indicator of shear sense in the Lake Char-Honey Hill mylonites. This has been corroborated at several localities through the observation of more easily interpreted and generally accepted microstructures. In those instances, fold asymmetry agrees with the sense of shear deduced from microstructural asymmetry (Stops 2 and 11).

Other Shear Sense Indicators - A large number of other mesoscopic and microscopic structural features can be used to interpret shear sense. These include asymmetric pressure shadows, asymmetric recrystallization tails on feldspar augen (figure 6), microfaults in feldspars (figure 7E) and almost any other asymmetric fabric. Simpson and Schmid (1984) review the more common of these. One less common asymmetric fabric which is present in some localities visited by this trip is an oblique transposed layering or foliaton. It is proposed that this develops in zones of high shear strain by extreme attenuation of short limbs of asymmetric intrafolial folds. The result is a true transposed layering.

Results of Shear Sense and Microstructural Studies

A wide variety of shear sense indicators have been observed in mylonites of the Lake Char-Honey Hill mylonite zone (figure 7). These include asymmetric intrafolial folds, asymmetric augen, extensional crenulations, sense of rotation at the margins of a small (1 m wide) shear zone, oblique transposed layering, oblique quartz c-axis asymmetry (figure 8), C and S structure, asymmetric mica "fish", oblique quartz grain shape, and a variety of other microstructures including microfaulted feldspar and displaced grains. The vast majority (approximately 95%) of these show that mylonites were formed during motion of the upper plate towards the northwest with respect to the lower plate (top-down or low-angle normal). The body of data is so large and the microstructures are so unambiguous (figure 7) that this conclusion is believed to be an absolute certainty. The temperatures ambient during mylonitization can be approximated by observations of microstructures. Plastic deformation of feldspar is suggestive of amphibolite facies temperatures (approximately greater than 525^{o}C) and the transition from brittle to ductile deformation of quartz is reflective of temperatures in the range of 300-350^{o}C. In most mylonites from the Lake Char-Honey Hill faults, both quartz and feldspar show the effects of dynamic recovery and recrystallization (figure 7D). This suggestion of amphibolite facies temperatures has been locally corroborated (Goldstein, 1982c) with geothermometry and is in agreement with the local occurrence of sillimanite in mylonite, although most mylonites do not contain an aluminosilicate phase. Locally, quartz can be observed deforming by crystal plastic mechanisms and feldspar by brittle mechanisms (figure 7E) suggesting a temperature of formation between 350 and 525^{o}C. In some very narrow zones, even quartz deforms by brittle mechanisms (figure 7F). This leads to the conclusion that motion on the Lake Char-Honey Hill fault began its motion at high temperature and at depths of between 12-17 km. Most mylonites were active during this early phase because all but the most mafic phases were deforming ductilly and were, therefore, weak. As temperatures and depths decreased and feldspars became stronger, deformation was concentrated in more narrow zones and at reasonably cold, near-surface conditions the deformation was localized in very narrow zones. It is difficult to place an absolute time span on this sequence and to know the sense of motion during the most brittle, latest motion. One of us (AG) speculates that the sequence spanned a geologically brief period during the Alleghanian orogeny and represents top-down motion during the entire period.

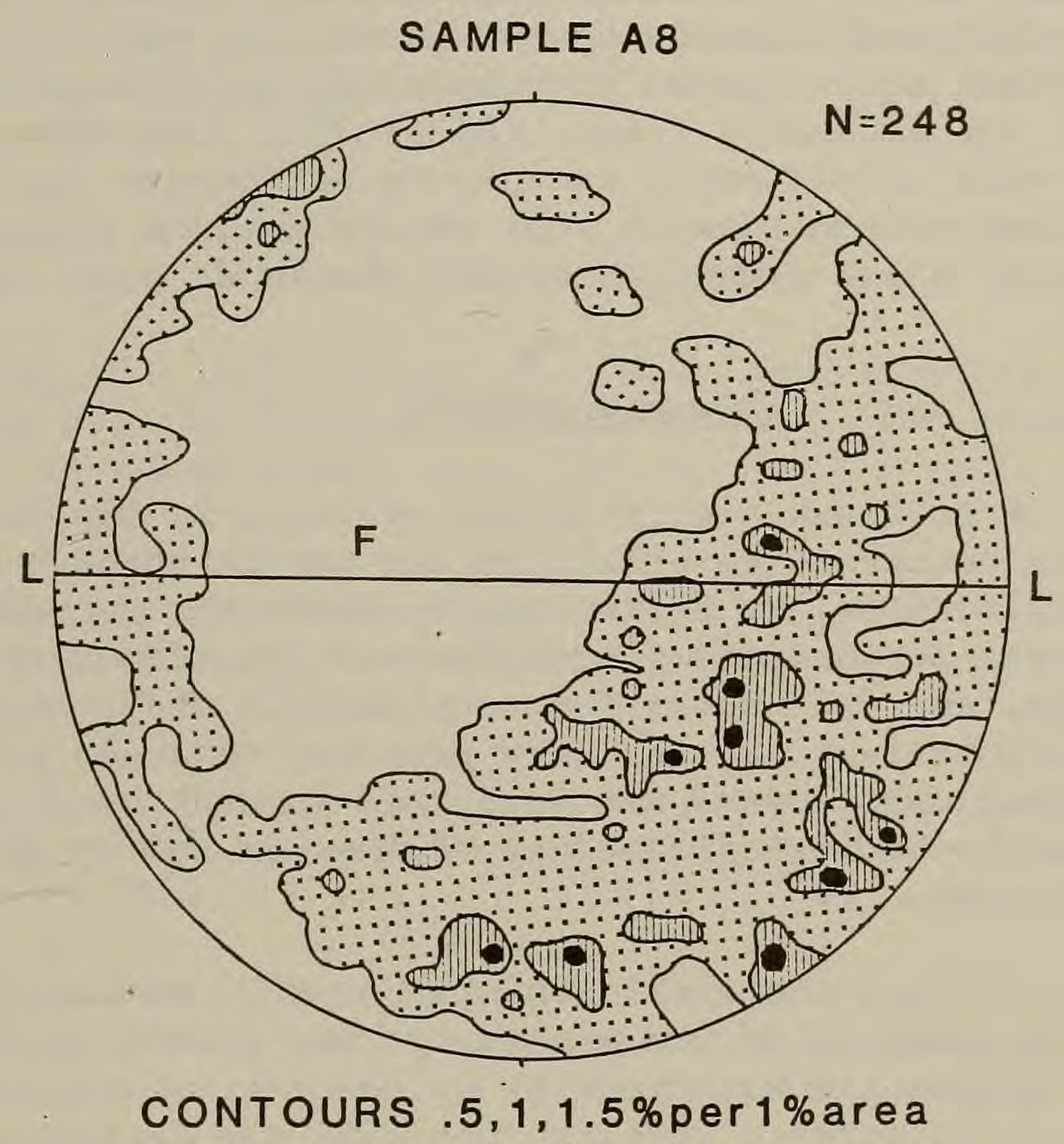

Figure 8. Lower hemisphere, equal-area diagram of quartz c-axes from mylonitized Hope Valley Alaskite in southern Oxford quadrangle (Goldstein's (1982) Stop 1). C-axes were measured from three mutually perpendicular thin-sections and are plotted such that lineation plots as east-west and horizontal with the northwest end of the lineation on the right (viewed looking southwest).

Results of microstructural studies of samples from the Bloody Bluff fault (Goldstein, Rodman and Hutton, in review) contrast with those noted above. All samples of the Bloody Bluff mylonites show thrust motion with a left-lateral component and ductile deformation of feldspars indicates that thrusting was a high-temperature event. Further, xenoliths of mylonite in unmylonitized gabbro require that mylonitization be no younger than Silurian. These conclusions provide a potential explanation for the local occurrence of thrust-motion indicators on the Lake Char-Honey Hill fault. It is likely that early thrusting occurred on the Honey Hill-Lake Char faults as well as the Bloody Bluff. Thrust indicators, then, could be localized in blocks which did not enjoy the later, top-down motion. Alternatively, top-down motion could have been preceeded immediately by a thrusting event (S. Mosher, pers. comm., 1984). The later phases of movement, however, were sufficiently intense to obliterate nearly all traces of thrusting. A final alternative is that thrust motions represent nothing more than "antithetic" shear developed around blocks or pods resistant to the mylonitization.

ACKNOWLEDGEMENTS

Owens would like to thank his principle advisors O. Don Hermes and Daniel P. Murray for constructive criticism and advice through the duration of this project; L.P. Gromet, R. Goldsmith, W. Danforth, N. Hamidzada, J. Bursnall and B. Jordan for helpful discussions of the often vexing problems of Avalonian geology, and G.E. Moore for considerable assistance in the forms of valuable discussion, and the very generous donation of field notes, samples, and thin sections. Owens was supported in part by a student research grant from the Geological Society of America and by NSF Grant EAR 8206149 (to O.D. Hermes).

Goldstein acknowledges the field assistance of D. MacLean, K. Linton, and S. Rothwell. Preparation of the manuscript was greatly aided by assistance from E. Rodman and was typed by B. DeGroat. Goldstein's work was funded by the Colgate University Research Council, the Research Corporation (Grant C-1754) and the Connecticut Geological and Natural History Survey.

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Starting Point:	Communter Parking Lot at exit 80, I395, Norwich, Conn. The parking lot is located immediately west of I395 off Route 82 adjacent to the Sheraton Motor Inn entrance. From parking lot, the trip continues west on Route 82. This trip leaves at 8:00 a.m.
Mileage:	Begins from right turn onto Route 82.

Cumulative	Interval	
1.6	1.6	Turn right onto South Road at sign for Camp Tadma.

South Road runs approximately parallel to and slightly north of the Honey Hill fault. Outcrops and cliffs on your left (north) are of thoroughly mylonitized Tatnic Hill Fm. (Biotite Gneiss of Lower Member and Fly Pond Member)

2.5	.9	Intersection with Swan Road and Bishop Road - Continue straight on South Road.
3.35	.85	Stop #1 - Power line crosses South Road; Park along power line road on south side of road.

STOP #1

Outcrops at parking area are of mylonitized biotite gneiss of the Tatnic Hill Fm. Locally present are folds with axial planes at high angles to the mylonitic foliation which may represent post-mylonitic deformation. Across the small swamp south of South Road are outcrops which Snyder (1964) mapped as plagioclase gneiss south of the Honey Hill fault (Quinebaug Fm.?); the trace of the Honey Hill fault occupies the swamp. We will traverse the Honey Hill mylonite zone from close to its base, along the power line road to the north, to its top in the Hebron Fm. Features of interest are noted on the schematic cross section (figure 9). Here the mylonite zone is .7 mi wide, so that this traverse will occupy considerable time, but the mesoscale structures are quite well developed and represent a wide variety of kinematic indicators as well as enigmatic features which can be discussed.

Cliffs immediately south of the power line and north of South Road expose marble of the Fly Pond Member of the Tatnic Hill Fm. Interlayered with the marble are quartzites and these quartzites are folded spectacularly. This is one of the best locations to discuss the origin and significance of folds in shear zones, a topic of considerable debate and uncertainty (see text). Care must be taken at this locality to remember that, because the lineation plunges obliquely

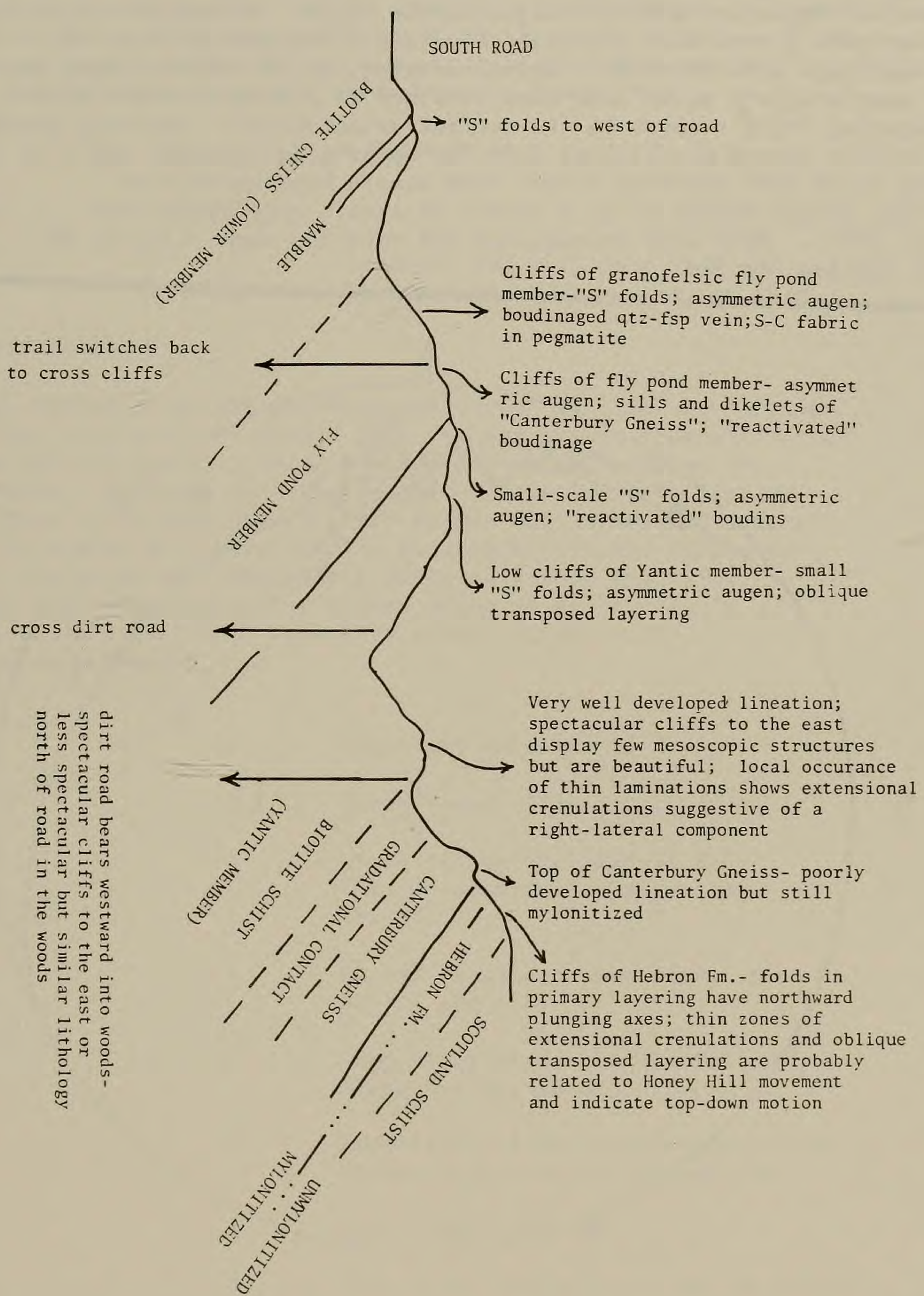


Figure 9. Schematic cross-section of Stop 1 noting mesoscopic structures of interest.

into the outcrop, only a component of fault motion would be parallel to the outcrop face making fold cross sections much less attenuated than if viewed in sections parallel to the lineation. Folds here have a wide variety of geometries: some have axial planes which parallel the mylonitic foliation whereas others have axial planes at a high angle to it. Some are highly attenuated isoclinal similar folds whereas others are smaller amplitude and wavelength buckle folds. It appears as if the quartzite layers were initially boudinaged and then folded. If this boudinage were related to mylonitization, as we believe, then the shear zone boundary would have been inclined at a steeper angle than the layering (with respect to its current orientation). Layering would have rotated toward parallelism with the shear zone boundary and folding could have resulted either from strain heterogeneities localized around boudin or as a result of strain rate variations (Platt, 1983). Fold axis orientation and rotation sense (figure 10) define top-down motion.

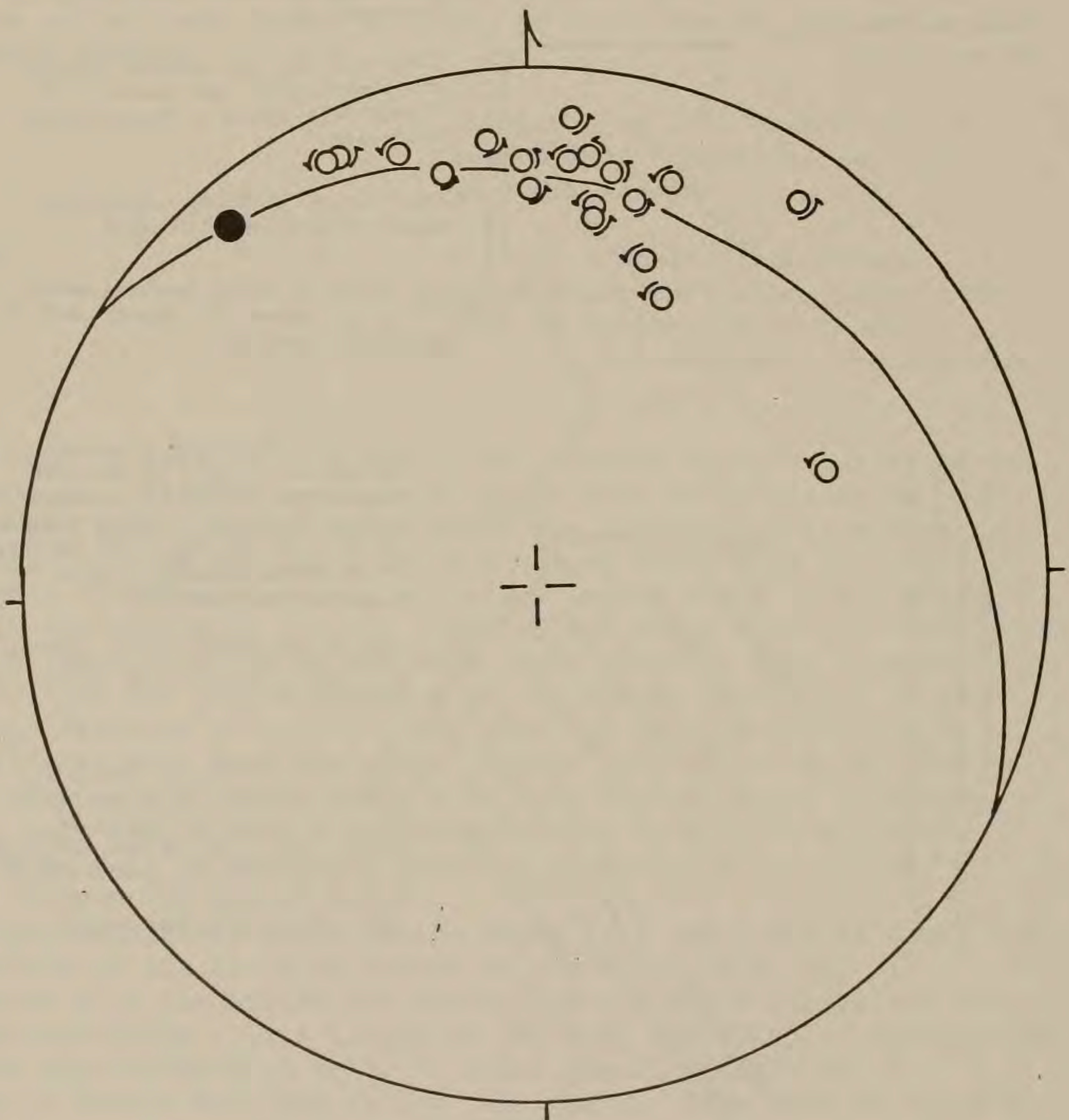


Figure 10. Lower hemisphere, equal-area plot of fold axes measured in the marble of Stop 1. Foliation is shown as the great circle and lineation as the solid dot.

Above the marble is a small pod of biotite gneiss enclosed by marble and calc-silicate of the Fly Pond Member. Within this block are some tenuous thrust-motion indicators including oblique foliations and asymmetric folds. It may be that this block was prohibited from enjoying the top-down motions as a result of its more ductile envelope.

Return to power line and walk northward along power line road. Numerous mesoscopic structures can be seen principally in the traverse over the first large hill; these are noted on figure 9. Continue along road to top of second large hill to observe mylonitized Canterbury Gneiss and spectacular mesoscopic structures in Hebron Fm.

Return to cars. Travel east on South Road.

Cumulative	Interval	
4.2	.85	Intersection with Swan Road and Bishop Road. Park by side of road.

STOP #2 (Optional)

Natural exposures at the northeastern corner of this intersection are of biotite gneiss of the Tatnic Hill Fm. and are an especially good locality to observe folds in mylonites and to collect samples for microstructures. Oriented thin-sections from this locality display muscovite "fish", oblique quartz grain shapes and asymmetric augen. Asymmetric folds are well developed in quartzofeldspathic layers in outcrops in the woods and immediately north on Bishop Road. The layering may have been pegmatitic dikes, veins or sills. It is interesting to note that fold asymmetry always agrees with microstructural asymmetry.

5.1	.9	Turn left onto Rt. 85
6.9	1.8	Cross under I395
9.0	2.1	Cross bridge over Yantic River into Norwich-Follow signs for Rt. 2E.
9.2	.2	At end of bridge turn right onto Rt. 2E and 12N
9.6	.4	Turn right across bridge-follow signs for Rt. 2E
9.6	.01	Immediately after bridge turn left-Follow signs for Rt. 2E and 12N
9.9	.3	Turn right - Rt. 2E
10.2	.3	Turn left. Follow signs for Rt. 165E

Cumulative	Interval	
15.3	5.1	Intersection with Rt. 164- Continue straight on Rt. 165
19.1	3.8	Turn left onto Gravel Road- Burdick Lane
19.6	.5	Pull over into "cleared" area on left.

STOP #3

Exposures on crest of hill to the left are of mylonitized lower plate and were first shown to the authors by Bobby Dixon and described in her guidebook article (Dixon, 1982; Stop #9). Here mylonitized Hope Valley Alaskite (?) displays an exceptional ribbon lineation and post-mylonitic folding. These post-mylonitic folds are uncommon but are present at several localities along the Lake Char fault. We speculate that these folds may be related to late stage displacements on the Lake Char fault.

20.1	.5	Return to Rt. 165 - turn left
21.2	1.1	Turn left onto Rt. 201
21.5	.3	Park on Rt. by waterfall

STOP #4

This short stop is to examine, briefly, one of the southernmost exposures of mylonite of the Lake Char fault. Here the Hope Valley Alaskite is mylonitic, displays a N50-60^{o}W trending lineation and has top-down microscopic kinematic indicators including oblique quartz grain shape and mica-fish. The obliquity of the muscovite fish can be seen mesoscopically by "fish flash".

Continue north on Rt. 201.

23.3	1.8	Intersection with Route 138 (Dixon's, 1982, Stop #10); Turn left onto Rt. 138 westbound.
27.1	3.8	Intersection with I395, turn right onto 395 northbound
40.1	13	Follow signs for Connecticut Turnpike and Route 6; Bear right (I395 bears left)
44.9	4.8	Park in Diner parking lot... lunch stop

Turn around and return westward on Connecticut Turnpike. The next five stops constitute a cross-section from Rhode Island basement terrane structurally upward to the Lake Char fault. The geology of this traverse is illustrated in figure 11 and 12. Structural data for domains along this traverse are shown in figure 13.

Cumulative	Interval	
45.9	1.0	Pull over by large roadcut

STOP #5

Domain I, Ponaganset Gneiss (fig. 14a). The lithology seen is typical of the western Ponaganset Gneiss. This is a medium gray, porphyritic granite gneiss. The lineation is seen in the N-S, sub-horizontal elongation and rotation of the 2-4 cm, pink phenocrysts (porphyroclasts). Note the absence of foliation to the extent that there is little or no preferential orientation of phenocrysts perpendicular to lineation. Note that the porphyritic gray granite includes xenoliths of the dark gray tonalite - granodiorite and is cut by the porphyritic, leucocratic granite and aplitic dikes.

46.4	.5	Small roadcut on westbound side of highway, park off shoulder of highway.

STOP #6 (optional)

Domain I, Ponaganset Gneiss. This outcrop is within 500 m of Plainfield Formation Quartzite and, as presently defined, the Hope Valley Shear Zone. Here the Ponaganset is weakly to moderately foliated (N trending, W dipping, fig. 13) where the microcline phenocrysts (porphyroclasts) are more thoroughly recrystallized, and these, the quartz aggregates, and the biotite clots are less equant perpendicular to the prominent lineation.

47.2	.8	Large roadcut, park off shoulder of highway.

STOP #7

Domain II, Plainfield Formation Quartzite (figure 15). This is one of the larger exposures of the massive, equigranular, metaquartzarenite typical of the quartzite members of the Plainfield Formation. Here foliation occurs as 1) a moderate to strong alignment of 0.5 mm muscovite and biotite lathes, and 2) 1-4 mm horizons of coarser, rectangular, recrystallized quartz grains. The strong N trending lineation persists. In the western part of the outcrop two pelitic layers (biotite schist) outline a isoclinal fold hinge (note enveloping surfaces, figure 15). However, within the enveloping surfaces the quartzite pelite layering has been rotated (or transposed)

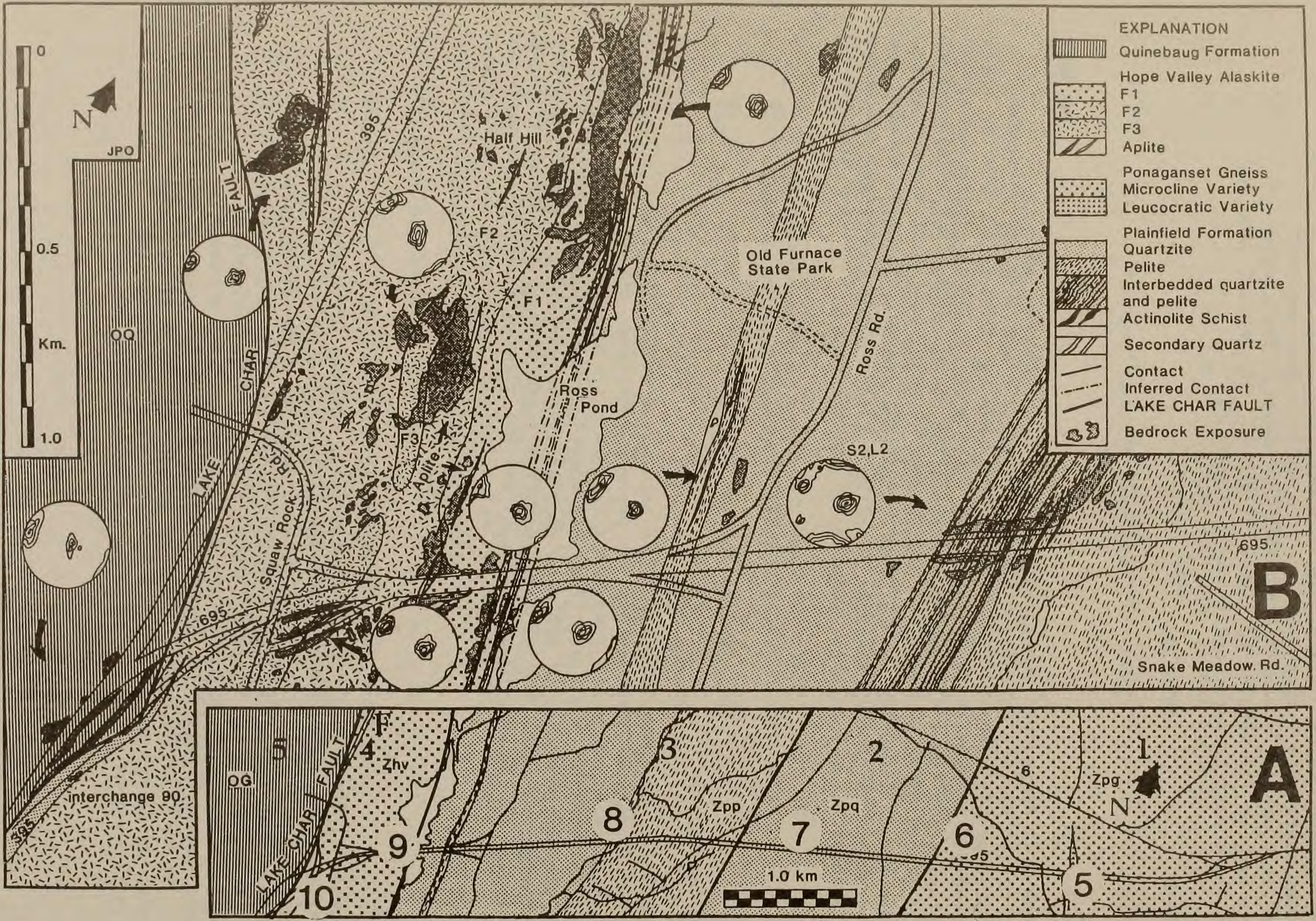


Figure 11. Geologic map of region around Stops 5 through 10, modified after Moore, 1983. Lower hemisphere, equal-area diagrams show the orientation of foliation and lineation, contours are 4.75, 9.5, 14.3, 28.6, and 38.1 percent per one percent area.

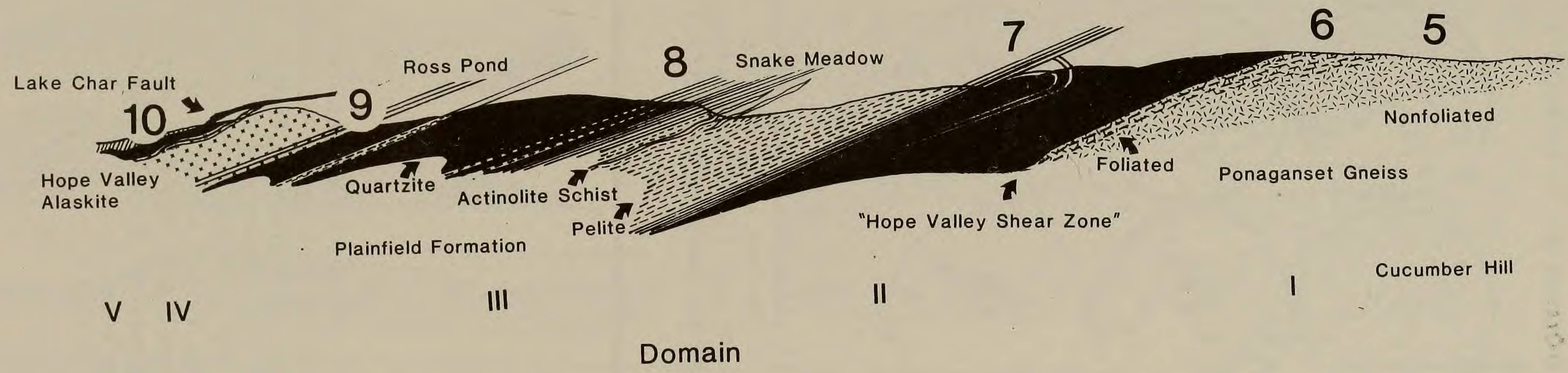


Figure 12. Schematic cross-section of region along the route of Stops 5 through 10.

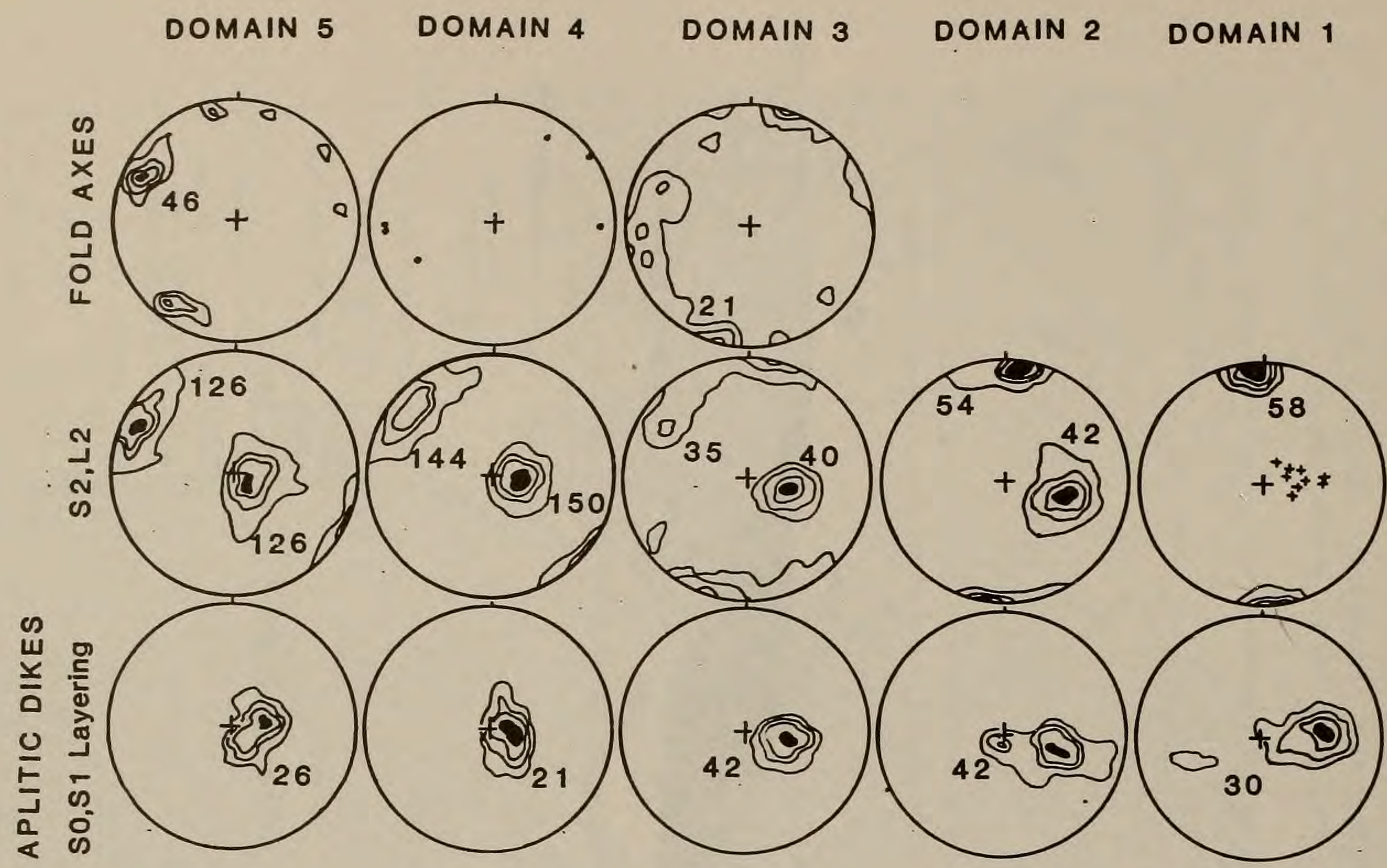
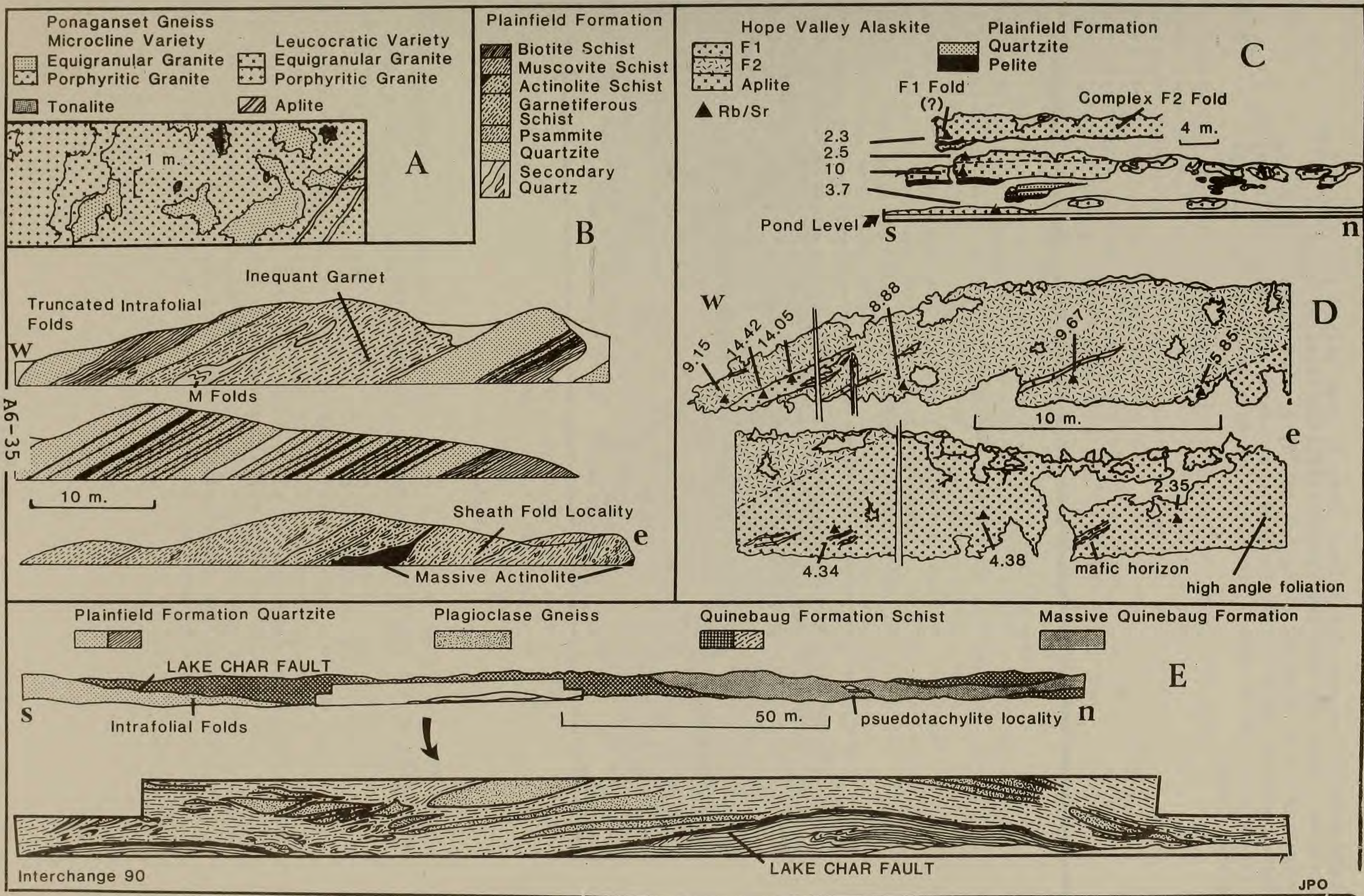


Figure 13. Synopsis of structural data for domains shown in figure 12 plotted or contoured on the Lowe hemisphere of equal-ara diagrams (S2 and L2 refer to foliation and lineation, respectively), numbers of data are noted, contours are the same as in figure 11.

→

Figure 14. Sketches of geological relationships at field trip stops along Rt. 695. A - Internal facies of Ponagansett Gneiss, Stop 5; B - Tape and compass map of Plainfield Formation facies at Stop 8, facing north; C - Tape and compass map of interlayered Plainfield Formation and Hope Valley Alaskite at Stop 10, facing west; Internal facies variation in Hope Valley Alaskite at Stop 9, facing north. Note Rb/Sr values increasing to the west and in aplites; E - Tape and compass map of roadcuts at Stop 10 exposing the trace of the Lake Char fault, facing west.


Ponaganset Gneiss
Microcline Variety
Equigranular Granite
Porphyritic Granite
Leucocratic Variety
Equigranular Granite
Porphyritic Granite
Tonalite
Aplite
1 m.
A
Plainfield Formation
Biotite Schist
Muscovite Schist
Actinolite Schist
Garnetiferous Schist
Psammite
Quartzite
Secondary Quartz
B
Inequant Garnet
Truncated Intrafolial Folds
W
M Folds
10 m.
Sheath Fold Locality
e
Massive Actinolite
Hope Valley Alaskite
F1
F2
Aplite
Rb/Sr
Plainfield Formation
Quartzite
Pelite
C
F1 Fold (?)
Complex F2 Fold
4 m.
2.3
2.5
10
3.7
Pond Level
s
n
W
9.15
14.42
14.05
8.88
9.67
5.85
D
10 m.
e
2.35
4.34
4.38
mafic horizon
high angle foliation
Plainfield Formation Quartzite
Plagioclase Gneiss
Quinebaug Formation Schist
Massive Quinebaug Formation
LAKE CHAR FAULT
E
s
Intrafolial Folds
50 m.
psuedotachylite locality
n
Interchange 90
LAKE CHAR FAULT
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into parallelism with foliation. Note 1) that within the enveloping surfaces, layering is truncated by foliation, indicative of segmentation of layering along foliation; 2) that poles to layering form a partial great circle roughly coincident with poles to foliation (figure 13), and 3) that lineation is crudely axial to this partial great circle.

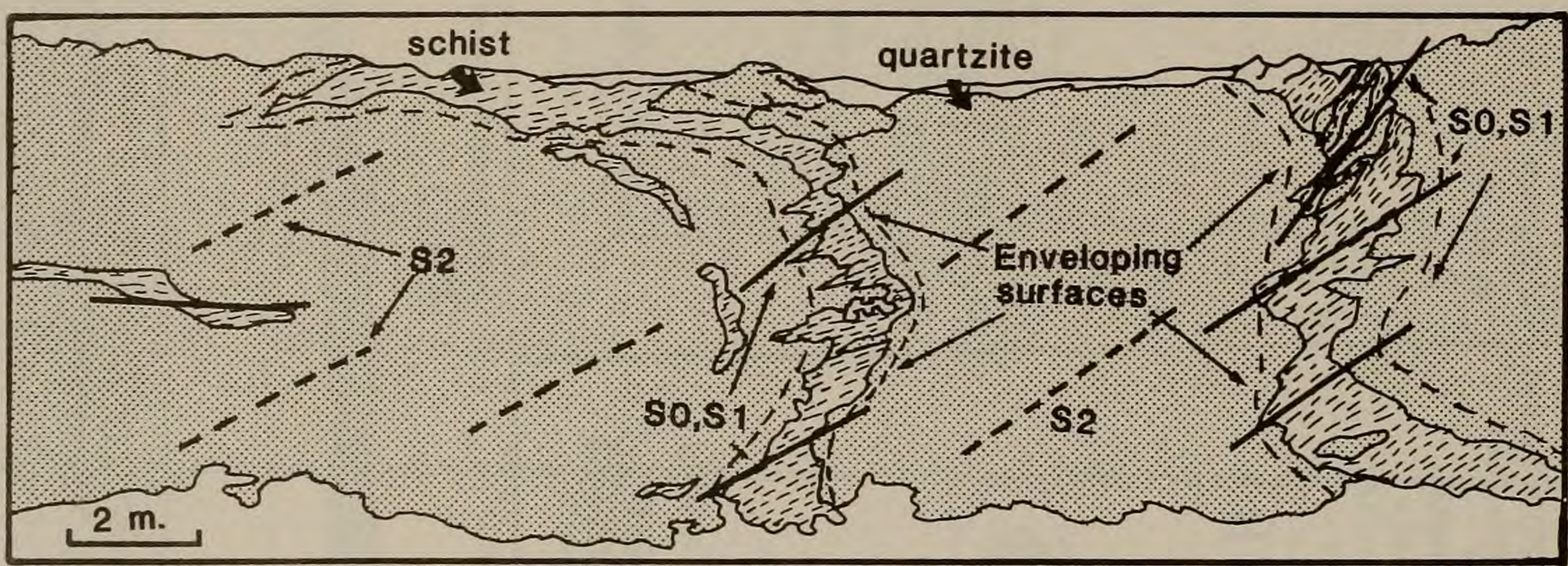

Figure 15. Sketch of roadcut at Stop 7 showing isoclinal fold hinges in bedding of the Plainfield Formation, facing north.

Cumulative	Interval	
48.1	.9	Large roadcut on westbound side of highway

STOP #8

Domain III, Plainfield Formation Pelite and Quartzite. In this outcrop some of the Plainfield Formation pelitic member and the gradational transition into a western quartzite member is well exposed (figure 14b). Foliation is well developed in the schists as a sinuous, undulatory surface defined by the preferred orientation of micas and the flattening of quartz and plagioclase, and is developed in the quartzites as at Stop 7. Lineation is well defined in the quartzites as a "mullion" structure and is less well defined in the schists as a preferred orientation of acicular minerals or a tight crenulation of micas in foliation. Asymmetric 1 cm micro-folds in foliation with axes that parallel lineation are quite common. Quartz rods and boudins are common within the schists. All of these structures probably were initiated during the isoclinal folding phase of deformation. An axial planar foliation may have served as a pre-existant slip plane for later shearing. Fold axis parallel crenulations, minor folds, quartz rods, and boudins may have been subsequently rotated into parallelism with the shear-related lineation. Both lineation orientations (N-S, NW) are present in this outcrop and the transition from N-S orientations at the eastern end of the cut to NW at the western end of the cut is apparently abrupt. We have not found the two lineations on the same surface but in the center of the roadcut adjacent foliation surfaces can have lineations with divergent orientations. Also found here are northeast-trending elongation lineations, sheath folds (eastern end of roadcut, figure 14b), truncated intrafolial folds and inequant, flattened garnets.

Cumulative	Interval	
48.9	.8	Continue west on 695, stop at large roadcut just west of Ross Pond. Cross road and walk east along path down to pond south of highway.

STOP #9

Domain IV, Hope Valley Alaskite; series of natural exposures from pond shore to the west. Figure 14C is a tape and compass map of these terraces. Note the interlayering of Plainfield Formation quartzites and pelites with the Hope Valley Alaskite. The layering contacts are highly sheared and the layering could be solely tectonic in origin. However, the Hope Valley Alaskite seen here is fine-grained and locally aplitic. This leads to the tenuous speculation that the Hope Valley Alaskite conformably intruded the Plainfield Formation and that the sill (?) contacts have been subsequently tectonically activated. This interlayering can be traced to the N as far as the base of Half Hill (figure 11b) where a general increase in Hope Valley grain size away from the interlayered zone can be observed. Structural features in the outcrop include 1) the well developed foliation and lineation, 2) the presence of a folded quartz vein, and 3) an asymmetric fold in the mylonitic foliation indicating oblique normal displacement parallel to lineation.

Return to outcrop on W bound side of highway (where vehicles are located).

Stop 9 continued - Domain IV, Hope Valley Alaskite. Figure 14C is a photomozaic derived map of this outcrop. Here the gradual transition from Hope Valley Alaskite is observed. The diffuse and arbitrary nature of the contact can be observed. Several aplitic dikes cut foliation. Stained slabs of the Hope Valley Alaskite when cut parallel to lineation and perpendicular to foliation reveal C-S surfaces throughout this domain (figure 16). With one exception they systematically indicate oblique normal displacement.

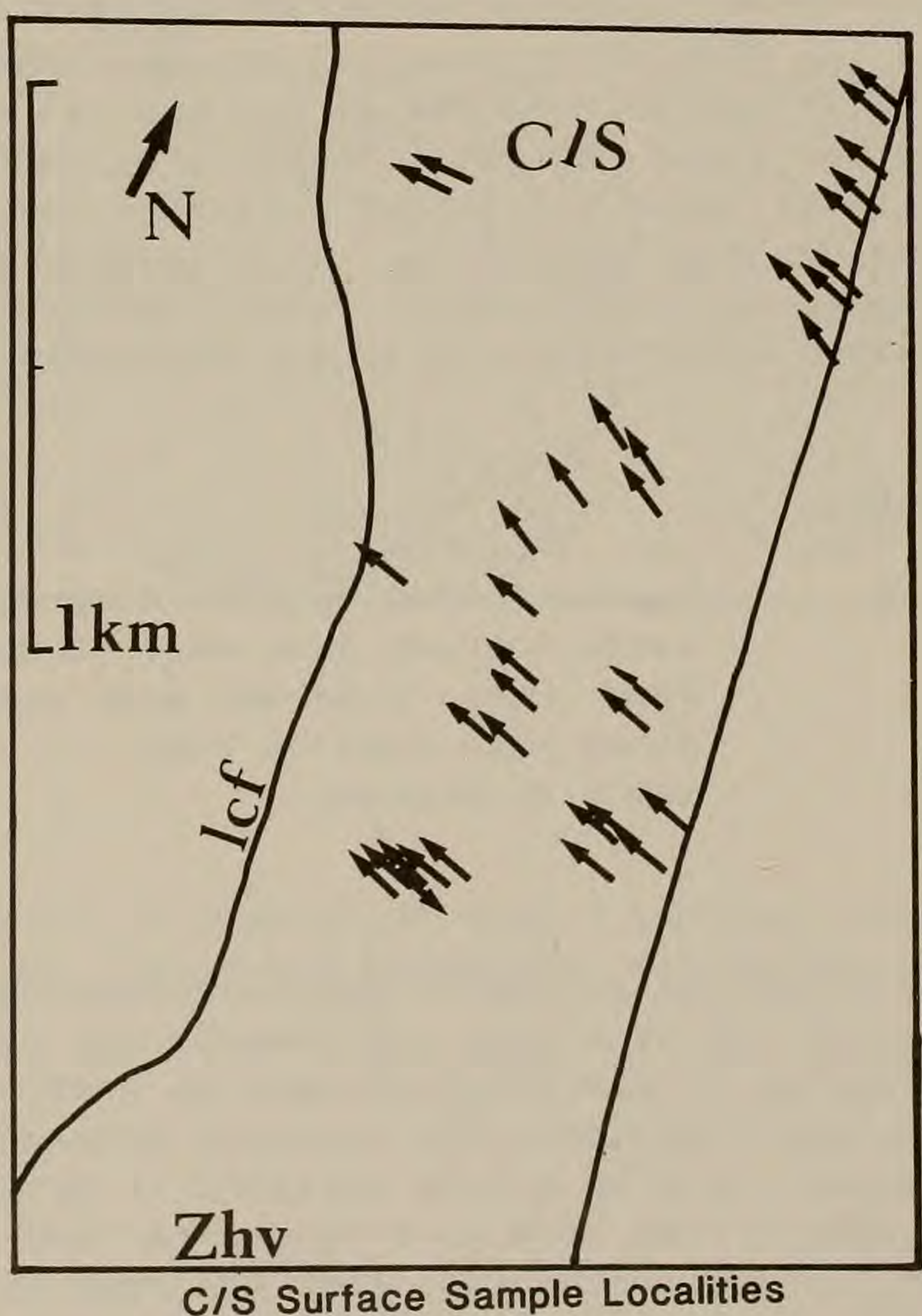

Figure 16. Direction of motion of upper plate of Lake Char fault determined from C and S fabric on stained slabs of Hope Valley Alaskite in domain IV (see figure 11).

		Continue west on 695, take first exit for Squaw Rock Road
Cumulative	Interval	
49.15	.25	Turn left (south) on Squaw Rock Road
49.4	.25	Park in wide shoulder on left side of road by telephone switching box. Walk north to to start of pole and cable guard rail on west side of road. Enter woods walking W and downhill through cleared area. Follow cleared area, through fence, to interchange 90. Walk south along N bound 395/695 past split in highway. Carefully cross highway.

STOP #10

Domain V, Quinebaug Formation and Plainfield Formation. Here the Lake Char fault is well exposed (figure 14). The rocks underlying the fault are recrystallized Plainfield Formation quartzites with abundant secondary quartz. Black Quinebaug Formation schist, massive grey Quinebaug Formation, and a coarsely porphyroblastic plagioclase gneiss overlie the fault. The plagioclase gneiss occurs in large tabular lenses which are concentrated at horizons in the Quinebaug Formation schist. These often have diffuse margins, rocks intermediate (in porphyroblast content) between the schist and the plagioclase gneiss are common and lenses are often imbricated (figure 14E). Owens speculates that 1) these represent primary layers of a composition preferential to porphyroblast growth during or before the first phase of metamorphism, 2) that this resulted in a competency contrast, due to which they were boudinaged during isoclinal folding and 3) that they have been rotated and imbricated during mylonitization. Measurements of intrafolial fold axes and rotational sense, from Plainfield Formation quartzites directly beneath the fault, yield a separation angle (figure 17b) consistent with a slip line parallel to the lineation of domain V and indicate oblique normal displacement. To the north in the outcrop plagioclase gneiss layers are cut by pseudotachylites (figure 14E), which have formed in thin seams parallel to foliation and intrude across foliation.

		Proceed northward on Squaw Rock Road which turns to the west.
Cumulative	Interval	
50.4	1.0	Turn right onto Green Hollow Rd.

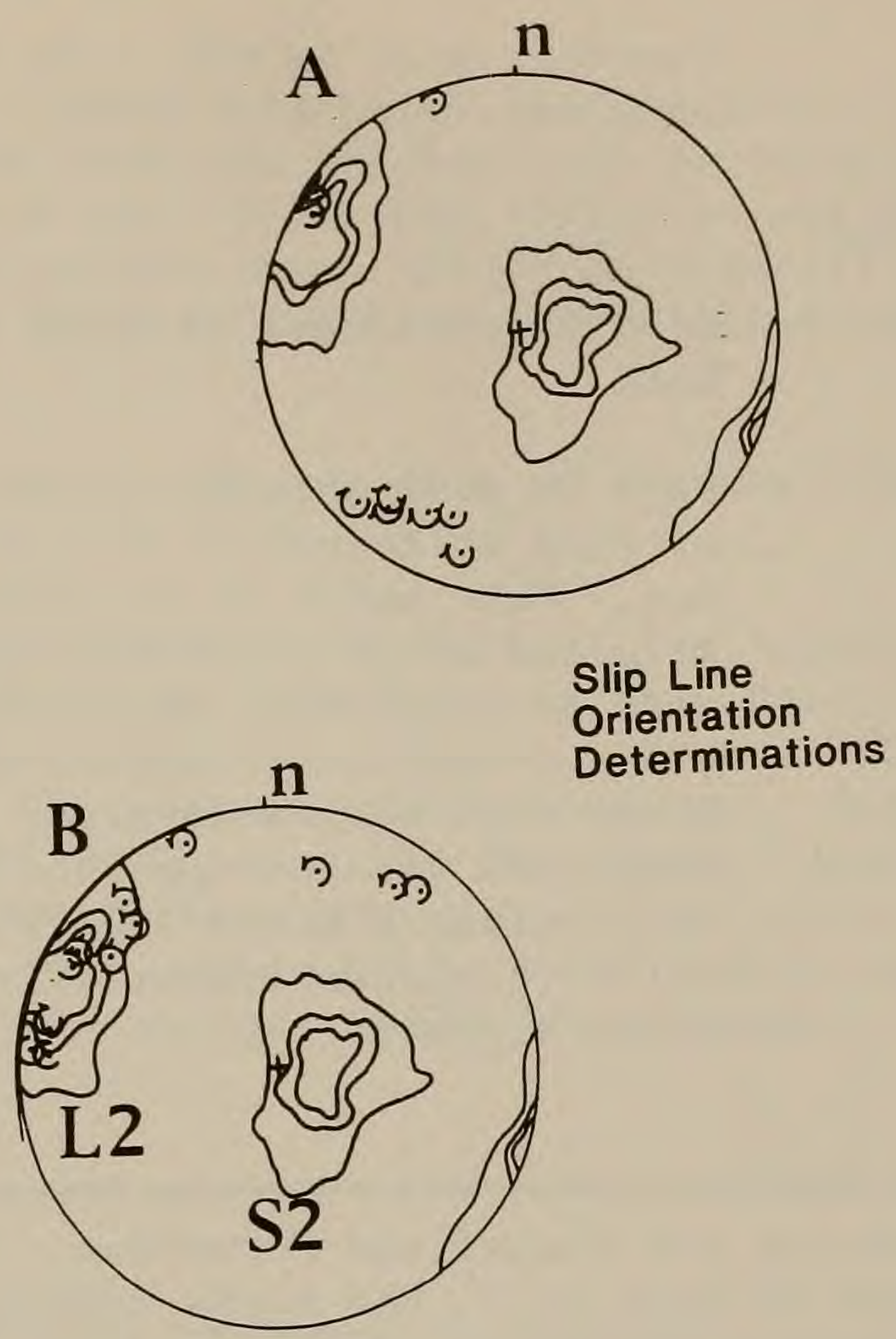

Figure 17. Separation angle determinations of motion direction of Lake Char fault at Stop 10 and an outcrop immediately north of Stop 10; lower hemisphere, equal-area projections.

Cumulative	Interval	
52.4	2.0	Stop sign, go straight across intersection
53.15	.75	Merge with Route 12 in Danielson
53.25	.1	Turn right at stop light
53.6	.35	Turn left onto I395 northbound
61.8	8.2	Take exit 97 for Route 44
61.9	.1	Turn right onto Route 44 eastbound
62.6	.7	Intersection with Route 21, continue on Route 44
64.3	1.7	Intersection with Tucker Hill Road. Park in cleared area at southeast side of intersection

STOP #11

The small roadcuts at this last stop expose several lithologies of the Plainfield formation as well as mesoscopic and microscopic structural evidence of top-down motion. The rocks are quite thoroughly mylonitized and lie within a zone either of fault repetition of the Quinebaug and Plainfield formations or some more complex repetition with mylonitization superimposed upon it. The Plainfield formation here consists of interlayered schist with plagioclase porphyroblasts and massive quartzite. The quartzite displays a spectacular oblique quartz grain shape and the schists, especially where interlayered with quartzites displays asymmetric intrafolial folds (figure 18), extended quartz veins, mica "fish", C and S fabric (figure 7A), and sigmoidal quartz pods all of which indicate top-down motion along the N60W trending mineral lineation. Many quartz veins are present and show crosscutting relationships suggestive of at least three stages of veining, the final one of which is epidote bearing. Another feature of interest here is the local occurrance of fabric forming chlorite.

Return westward on Route 44, I395 is approximately 2.1 miles. To get to the starting point of Goldstein's (1982) field trip to the Lake Char mylonite zone in Webster, Mass. area, which also cites evidence for top-down motion, proceed northwards to exist 100, Wilsonville, Connecticut and follow the directions from there.

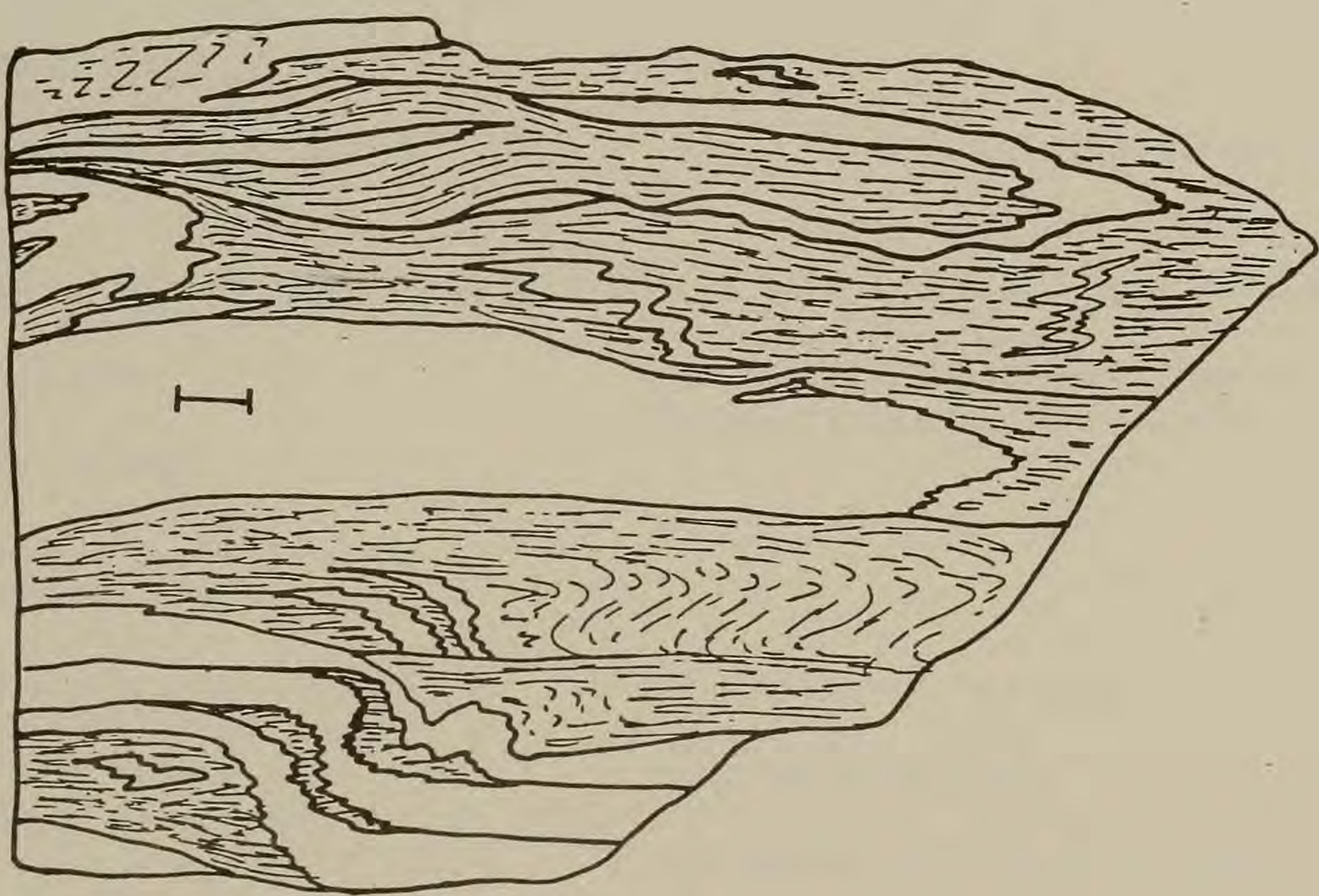

Figure 18. Sketch of folds in Plainfield Formation mylonites at Stop 11. Bar scale is 1 cm, sketched from a slab cut parallel to lineation.